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THE

ELEMENTS

OF

EXPERIMENTAL CHEMISTRY,

BY

WILLIAM HENRY, M.D. F.R.S.

VICE-PRESIDENT OF THE LITERARY AND PHILOSOPHICAL, AND NATURAL HISTORY
SOCIETIES OF MANCHESTER; MEMBER OF THE ROYAL MEDICAL AND WERNERIAN
SOCIETIES OF EDINBURGH; THE MEDICO-CHIRURGICAL AND GEOLOGICAL
SOCIETIES OF LONDON; THE PHYSICAL SOCIETY OF JENA; THE NATURAL HISTORY SOCIETY OF MOSCOW; THE LITERARY AND PHILOSOPHICAL SOCIETY OF NEW-YORK, &c. &c.

THE ELEVENTH EDITION,

COMPREHENDING ALL THE RECENT DISCOVERIES; AND ILLUSTRATED WITH TEN
PLATES BY LOWRY, AND SEVERAL ENGRAVINGS ON WOOD.

IN TWO VOLUMES.
WITH NUMEROUS RECOMMENDATIONS.
VOL. I.

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RECOMMENDATIONS.

February 12th, 1831.

Mr. Robert Desilver,

Dear Sir—

I cheerfully state my belief, that this new edition of Dr. Henry's Chemistry, will, like the preceding editions, prove to be among the best cotemporaneous elementary treatises, on the science to which it is devoted.

I am, Sir,
Your obedient servant,
ROBERT HARE.

February 15th, 1831.

The Elements of Chemistry of Dr. Henry have always been esteemed as a standard work, and as such have been deservedly popular with the American public. The eleventh and last edition, which has been recently reprinted by Mr. Robert Desilver, has been corrected by the author with his usual abilities, and contains all the important facts and discoveries in the science, which have been contributed, since the appearance of the tenth. Entertaining these views of the merits of Dr. Henry's work, we recommend it to the American public.

FRANKLIN BACHE, M.D.

February 15th, 1831.

Dear Sir—

I am rejoiced to find that you have republished the Eleventh and Last Edition of Henry's Chemistry.

Notwithstanding the numerous works which have recently appeared on the same subject, the great value of Dr. Henry's Elements is but very slightly impaired. Its general principles of classification I have always thought just and natural, and its details of chemical phenomena, are so minute and close, as to furnish one of the most useful guides to the chemical student.

Wishing you great success in your enterprise,

I am, yours truly,
JACOB GREEN.

Mr. Robert Desilver.

February 15th, 1831.

Dear Sir—

I have carefully examined the eleventh edition of "the Elements of Experimental Chemistry by William Henry, M.D., &c." published by you, and believe it to comprise all the recent discoveries and improvements in the science, adapting the work (which has always been considered of standard excellence) to the present advanced state of the medical sciences and the useful arts, and rendering it equal if not superior to any work of the same class now extant, either for the purpose of elementary instruction to the medical student, or as a work of reference to the practical artisan.

Yours, &c.
CALEB B. MATTHEWS.

Mr. Robert Desilver.

TO

JOHN DALTON, F.R.S.

PRESIDENT OF THE LITERARY AND PHILOSOPHICAL SOCIETY OF MANCHESTER;
CORRESPONDING MEMBER OF THE ACADEMY OF SCIENCES
OF THE ROYAL INSTITUTE OF FRANCE, &c.,

AS A

TESTIMONY OF RESPECT

FOR THE

ZEAL, DISINTERESTEDNESS, AND SUCCESS,

WITH WHICH

HE HAS DEVOTED HIMSELF TO THE ADVANCEMENT OF

CHEMICAL PHILOSOPHY,

THIS WORK IS INSCRIBED,

BY HIS FRIEND,

THE AUTHOR.

Manchester, November, 1829.

PREFACE

TO THE ELEVENTH EDITION.

The Science of Chemistry, during the interval which has elapsed since the publication of the last edition of these volumes, has continued to advance with steady and uninterrupted progress. If its career has not been marked by discoveries of equal importance with those, which, at periods not very remote, shed a lustre over the whole extent of chemical philosophy, yet it may be distinctly traced in the exhibition of new substances, both elementary and compounded; in fresh lights thrown upon analogies, which were before imperfect; in the firmer establishment of some general principles, and the restriction of others which had been too universally applied. Not only have the foundations of the science been strengthened, but the superstructure has been improved in symmetry, as well as in durability.

The great laws of combination in definite and in multiple proportions, on which the Atomic Theory mainly rests, have, more especially, derived increased support from the accumulated mass of evidence. In too many instances, it must be acknowledged, we have not, even yet, attained all the precision that is desirable, as to the true proportions in which bodies combine. Nor can we arrive at this degree of certainty, until the relative weights of some of the elementary gases have been determined, with the aid of the most refined instruments, and with the most elaborate and scrupulous correctness. It were to be wished, indeed, that this should be attempted under the auspices of some one of those learned societies, which have been instituted for the promotion of science; and that the investigation should be confided to a commission of its members, whose skill, experience, and fidelity, would be a pledge for the accuracy of the results. The precise admeasurement of an arc of the meridian was not more important to astronomical truth, than the exact determination of the specific gravities of the elementary gases is to chemical philosophy.

It is impossible to direct our views to the future improvement of this wide field of science, without deeply lamenting the privation, which we have lately sustained, of two of its most successful cultivators, Sir Humphry Davy and Dr. Wollaston,—at a period of life, too, when it seemed reasonable to have expected, from each of them, a much longer continuance of his invaluable labours. To those high gifts of nature, which are the characteristics of genius, and which constitute its very essence, both those eminent men united an unwearied industry and zeal in research, and habits of accurate reasoning, without which even the energies of genius are inadequate to the achievement of great scientific designs. With these excellencies, common to both, they were nevertheless distinguishable by marked intellectual peculiarities. Bold, ardent, and enthusiastic, Davy soared to greater heights;

he commanded a wider horizon; and his keen vision penetrated to its utmost boundaries. His imagination, in the highest degree fertile and inventive, took a rapid and extensive range in pursuit of conjectural analogies, which he submitted to close and patient comparison with known facts, and tried by an appeal to ingenious and conclusive experiments. He was imbued with the spirit, and was a master in the practice, of the inductive logic; and he has left us some of the noblest examples of the efficacy of that great instrument of human reason in the discovery of truth. He applied it, not only to connect classes of facts of more limited extent and importance, but to develop great and comprehensive laws, which embrace phenomena, that are almost universal to the natural world. In explaining those laws, he cast upon them the illumination of his own clear and vivid conceptions;—he felt an intense admiration of the beauty, order, and harmony, which are conspicuous in the perfect CHEMISTRY OF NATURE;—and he expressed those feelings with a force of eloquence, which could issue only from a mind of the highest powers, and of the finest sensibilities. With much less enthusiasm from temperament, Dr. Wollaston was endowed with bodily senses of extraordinary acuteness and accuracy, and with great general vigour of understanding. Trained in the discipline of the exact sciences, he had acquired a powerful command over his attention, and had habituated himself to the most rigid correctness, both of thought and of language. He was sufficiently provided with the resources of the mathematics, to be enabled to pursue, with success, profound inquiries in mechanical and optical philosophy, the results of which enabled him to unfold the causes of phenomena, not before understood, and to enrich the arts, connected with those sciences, by the invention of ingenious and valuable instruments. In CHEMISTRY, he was distinguished by the extreme nicety and delicacy of his observations; by the quickness and precision, with which he marked resemblances and discriminated differences; the sagacity, with which he devised experiments, and anticipated their results; and the skill, with which he executed the analysis of fragments of new substances, often so minute as to be scarcely perceptible by ordinary eyes. He was remarkable, too, for the caution, with which he advanced from facts to general conclusions; a caution which, if it sometimes prevented him from reaching at once to the most sublime truths, yet rendered every step of his ascent a secure station, from which it was easy to rise to higher and more enlarged inductions. Thus these illustrious men, though differing essentially in their natural powers and acquired habits, and moving, independently of each other, in different paths, contributed to accomplish the same great ends—the evolving new elements; the combining matter into new forms; the increase of human happiness by the improvement of the arts of civilized life; and the establishment of general laws, that will serve to guide other philosophers onwards, through vast and unexplored regions of scientific discovery.

Of the alterations which have been made in preparing this edition for the press, it is sufficient to speak in general terms; for it would be equally tedious and useless to notice all the additions and modifications, that have arisen out of further reflection, or have been rendered expedient by the progress of chemical knowledge. From the general arrangement of bodies into ELECTRO-POSITIVE and ELECTRO-NEGATIVE, I have seen no reason to deviate, though it appears to me to be entitled to preference, on no better ground than that of convenience. Classifications of facts, it must be remembered, have no prototypes in nature. They are merely artificial contrivances, founded on general analogies; and they are liable to be changed, and even subverted, if shown to rest on deficient or erroneous data, or to be incapable of comprehending newly discovered facts.

Of the numerous and important memoirs, which have appeared during the few last years in the transactions of societies and in the scientific journals, I have endeavoured to give a condensed yet clear outline; and have retained the practice of referring to authorities, because it enables the reader to consult the original documents, on any topic that may coincide with his peculiar pursuit. To gain room for the new matter, I have abridged and retrenched whatever seemed to me of least importance; and, in the chapter of ADDENDA, at the close of the second volume, I have supplied a few deficiencies, and have given a view of discoveries to the latest period, which the publication will allow.

Though no pains have been spared, to render these volumes a faithful abstract of the present state of CHEMICAL SCIENCE, yet, in executing a work, the subject of which is so comprehensive, and which involves not only a large class of general principles, but an almost infinite number of minute details, it can scarcely be expected that some errors should not have escaped me. These, I trust, however, are neither numerous nor important; and I shall be thankful for their correction, whenever they may be pointed out with the candour characteristic of philosophers, who are sincerely anxious for the advancement of knowledge, and who seek, by the detection and rectification of error, no other object than the attainment of truth.

Manchester, November, 1829.

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ELEMENTS

OF

EXPERIMENTAL CHEMISTRY.

PART I.

CHAPTER I.

OF A CHEMICAL LABORATORY AND APPARATUS.

A CHEMICAL laboratory, though extremely useful, and even essential, to all who embark extensively in the practice of chemistry, either as an art, or as a branch of liberal knowledge, is by no means required for the performance of those simple experiments, which furnish the evidence of the fundamental truths of the science. A room that is well lighted, easily ventilated, and destitute of any valuable furniture, is all that is absolutely necessary for the purpose. It is advisable, indeed, that the construction of a regular laboratory should be deferred, till the student has made some progress in the science; for he will then be better qualified to accommodate its plan to his own peculiar views and convenience.

It is scarcely possible to offer the plan of a laboratory, which will be suitable to every person, and to all situations; or to suggest any thing more than a few rules that should be generally observed. Different apartments are required for the various classes of chemical operations. The principal one may be on the ground floor; twenty-five feet long, sixteen or eighteen wide, and open to the roof, in which there should be contrivances for allowing the occasional escape of suffocating vapours. This will be destined chiefly for containing furnaces, both fixed and portable. It should be amply furnished with shelves and drawers, and with a large table in the centre, the best form of which is that of a double cross. Another apartment may be appropriated to the minuter operations of chemistry; such as those of precipitation on a small scale, the processes that require merely the heat of a lamp, and experiments on the gases. In a third of smaller size, may be deposited accurate balances, and other instruments of considerable nicety, which would be injured by the acid fumes that are constantly spread through a laboratory.

The following are the principal instruments that are required in chemical investigations; but it is impossible, without entering into very minute details, to enumerate all the apparatus that should be in the possession of a practical chemist. Those who are desirous of fuller information are referred to an elaborate work of Mr. Faraday, in one vol. 8vo., entitled "Chemical Manipulation," in which they will find a distinct account of the apparatus adapted to purposes of demonstration, analysis, and research, with clear and ample instructions for the use of it.

SECTION I.

Of Apparatus for General Purposes.

I. Furnaces. These may be formed either of solid brickwork, or of such materials as admit of their removal from place to place.

The directions, generally laid down in elementary books of chemistry for the construction of FIXED FURNACES appear to me deficient in precision, and such as a workman would find it difficult to put in practice. I have, therefore, given plans and sections, in the 7th and 8th plates, of the various kinds of furnaces; and, in the Appendix, minute instructions will be found for erecting them. (See the description of the 7th and 8th plates.)

The furnaces of most general utility are, 1st, the *Wind Furnace*, in which an intense heat is capable of being excited for the fusion of metals, &c. In this furnace, the body submitted to the action of heat, or the vessel containing it, is placed in contact with the burning fuel. Fig. 60 exhibits one of the most common construction. Fig. 61 is the section of a wind furnace, the plan of which was obligingly communicated to me by Mr. Knight, of Foster-lane, London; to whom, also, I am indebted for that represented, fig. 62. The wind furnace of Mr. Chevenix is shown by fig. 74. 2dly, The *Evaporating Furnace*, is formed of iron plates, joined together by rabbeting, and placed over horizontal returning flues of brick. Figs. 64 and 65, are two views of this furnace as recommended by Mr. Knight. When evaporation is performed by the naked fire, the vessel may be placed on the top of the furnace, fig. 60 or 61; and when effected through the intervention of a water bath, a shallow kettle of water, in which is placed the evaporating-dish and its contents, may be set in the same situation. 3dly, The plan of a *Reverberatory Furnace* is exhibited by figs. 66, 67, and 68. 4thly, *The Furnace for distilling by a Sand Heat* is constructed by setting upon the top of the brickwork, fig. 60, the iron pot, fig. 71; a door being made in the side of the furnace for introducing fuel. Distillation by the naked fire is performed with the wind furnace, figs. 62, 63. 5thly, The *Cupelling* or *Enamelling Furnace*, is shown by figs. 69, 70.

Portable furnaces, however, are amply sufficient for all the purposes of the chemical student, at the outset of his pursuit. The one which I prefer is that shown by figs. 58 and 59, plate vi. It was originally contrived, I believe, by Mr. Schmeisser; and is made with considerable improvements, and sold by the dealers in chemical apparatus. Its size is so small, that it may be set on a table, and the smoke may be conveyed by an iron pipe, into the chimney of the apartment. In the furnace, as it is usually sold, the chimney, adapted for distillation with a sand heat, passes directly through the sand-bath, the form of which is necessarily, when thus constructed, a very inconvenient one. I have found it a great improvement to make the aperture for the chimney at *k*. This allows us to have a sand-bath of the usual shape, as shown by fig. 59; or even to place evaporating dishes, or a small boiler, on the top of the furnace. The aperture of the side flue may be closed by a stopper, when we dispose the furnace as shown by fig. 58. Dr. Black's furnace is generally made of a larger size, and is adapted to operations on a more considerable scale. (See figs. 72 and 73.) Both these furnaces are constructed of thin iron plates, and are lined with fire-clay. They will be minutely described in the references to the plates.

For the purpose of exciting a sudden heat, and of raising it to great intensity, nothing can be better adapted than a very simple, cheap, and ingenious furnace, contrived by Mr. Charles Aikin, fig. 55. It is formed out of pieces of black-lead melting pots, in a manner to be described in the Appendix, and is supplied with air by a pair of double bellows, *d*. By a slight alteration, this furnace may occasionally be employed for the operation of cupelling. (See fig. 57.)

II. For containing the materials, which are to be submitted to the action of heat in a wind furnace, vessels called CRUCIBLES are employed. They are most commonly made of a mixture of fire-clay and sand, occasionally with the addition of plumbago, or black-lead. The Hessian crucibles are best adapted for supporting an intense heat without melting; but they are liable to crack when suddenly heated or cooled. The porcelain ones, made by Messrs. Wedgwood, are of much purer materials, but are still more apt to crack on sudden changes of temperature; and, when used, they should, therefore, be placed in a common crucible of larger size, the interval being filled with sand. The black-lead crucibles resist very sudden changes of temperature, and may be repeatedly used; but they are destroyed when some saline substances (such as nitre) are melted in them, and are consumed by a current of air. For certain purposes, crucibles are formed of pure silver or platinum. Their form varies considerably, as will appear from inspecting plate vi. figs. 49, 50, 51, and 54. It is necessary, in all cases, to raise them from the bars of the grate, by a stand, fig. 53. *a* or *b*. For the purposes of submitting substances to the continued action of a red heat, and with a considerable surface exposed to the air, the hollow arched vessel, with a flat bottom, fig. 52, termed a *muffle*, is commonly used. In fig. 69, *d*, *e*, the muffle is shown, placed in a furnace for use.

III. EVAPORATING VESSELS should always be of a flat shape, so as to expose them extensively to the action of heat. (See a section of one, fig. 12.) They are formed of glass, of earthenware, and of various metals. Those of glass are with difficulty made sufficiently thin, and are often broken by change of temperature; but they have a great advantage in the smoothness of their surface, and in resisting the action of most acid and corrosive substances. Evaporating vessels of porcelain or Wedgwood's ware, are next in utility, are less costly, and less liable to be cracked. They are made both of glazed and unglazed ware. For ordinary purposes the former are to be preferred; but the unglazed should be employed when great accuracy is required, since the glazing is acted on by several chemical substances. Evaporating vessels of glass or porcelain are generally bedded, up to their edge, in sand (see fig. 65); but those of various metals are placed immediately over the naked fire. When the glass or porcelain vessel is very thin, and of small size, as a watch glass for example, it may be held by means of a small prong, represented under fig. 12; or it may be safely placed on the ring of the brass stand, plate i. fig. 13, and the flame of an Argand's lamp, cautiously regulated, may be applied beneath it. A lamp thus supported, so as to be raised or lowered, at pleasure, on an upright pillar, to which rings, of various diameters, are adapted, will be found extremely useful; and, when a strong heat is required, it is advisable to employ a lamp, furnished with double concentric wicks. A lamp for burning spirit of wine will, also, be found very convenient, especially if provided (as they now generally are) with a glass cap to cover the wick when not in use, which, being fitted by grinding, prevents the waste of the spirit by evaporation.

IV. In the process of evaporation, the vapour for the most part is allowed to escape; but of certain chemical processes, the collection of the volatile portion is the principal object. This process is termed DISTILLATION. It is performed in vessels of various forms and materials. The common still is so generally known, that a representation of it in the plates was deemed unnecessary. It consists of a vessel, generally of copper, shaped liked a tea-kettle, but without its spout and handle. Into the opening of this vessel, instead of a common lid, a hollow moveable head is affixed, which ends in a narrow, open pipe. This pipe is received into another tube of lead, which is twisted spirally, and fixed in a wooden tub, so that it may be surrounded by cold water. (Fig 40, *dd.*) When the apparatus is to be used, the liquid intended to be distilled is poured into the body of the still, and the head is fixed in its place, the pipe, which terminates it, being received into the leaden worm. The liquid is raised into vapour, which passes into the worm, is there condensed by the surrounding cold water, and flows out at the lower extremity.

The common still, however, can only be employed for volatilizing substances that do not act on copper, or other metals, and is, therefore, limited to very few operations. The vessel, fig. 2, is of glass, or earthenware, and is also intended for distillation. It is termed an *alembic*, and consists of two parts; the body *a* for containing the materials, and the head *b* by which the vapour is condensed: the pipe *c* conveying it to a receiver. Vessels, termed *retorts*, however, are more generally used. Fig. 1, *a*, shows the common form, and fig. 13, *a*, represents a stoppered or tubulated retort. Retorts are made of glass, of earthenware, or of metal. When a liquid is to be added at distant intervals during the process, the best contrivance is that shown in fig. 26, *a*, consisting of a bent tube, with a funnel at the upper end. When the whole is introduced at first, it is done either through the tubulure, or, if into a plain retort, through the funnel, fig. 10, by means of which the liquid may be poured in, without touching the inside of the retort neck.

To the retort, a *receiver* is a necessary appendage; and this may either be plain, fig. 1, *b*, or tubulated, as shown by fig. 30, *b*. To some receivers a pipe is added (fig. 13, *b*), which may enter a little way into a bottle set beneath. This vessel, which is principally useful for enabling us to remove the distilled liquid, at different periods of the process, is termed a *quilled receiver*. For some purposes, it is expedient to have the quilled part accurately ground to the neck of the bottle, *c*, which should then be furnished with a tubulure, or second neck, having a ground stopper, and should be provided, also, with a bent tube, to be occasionally applied, for conveying away any gases that may be produced. The condensation of the vapour is much facilitated, by lengthening the neck of the retort with an *adopter* (fig. 11), the wider end of which slips over the retort neck, while its narrow extremity is admitted into the mouth of the receiver. (See fig. 63.)

Heat may be applied to the retort in several modes. When the vessel is of earthenware, and when the distilled substance requires a strong heat to raise it into vapour, the naked fire is applied, as shown fig. 63. Glass retorts are generally placed in heated sand (fig. 59); and, when of a small size, the flame of an Argand's lamp, or of a gas-burner, cautiously regulated, may be conveniently used (fig. 13).

In several instances, the substance raised by distillation is partly a condensable liquid, and partly a gas, which is not condensed till it is brought into contact with water. To effect this double purpose, a series of receivers, termed *Woulfe's Apparatus*, is employed. The first receiver (*b*. fig. 30) has a right angled glass tube, open at both ends, fixed into its tubulure; and the other extremity of the tube is made to terminate beneath the surface of distilled water, contained, as high as the horizontal dotted line, in the three-necked bottle *c*. From another neck of this bottle, a second pipe proceeds, which ends, like the first, under water, contained in a second bottle *d*. To the central neck a straight tube, open at both ends, is fixed, so that its lower end may be a little beneath the surface of the liquid. Of these bottles any number may be employed that is thought necessary.

The materials being introduced into the retort, the arrangement completed, and the joints secured in the manner to be presently described, the distillation is begun. The condensable vapour collects in a liquid form in the balloon *b*, while the evolved gas passes through the bent pipe, beneath the surface of the water in *c*, which continues to absorb it till saturated. When the water of the first bottle can absorb no more, the gas passes, uncondensed, through the second right-angled tube, into the water of the second bottle, which, in its turn, becomes saturated. Any gas that may be produced, which is not absorbable by water, escapes through the bent tube *e*, and may be collected, if necessary.

Supposing the bottles to be destitute of the middle necks, and, consequently, without the perpendicular tubes, the process would be liable to be interrupted by an accident: for if, in consequence of a diminished temperature, an absorption or condensation of gas should take place, in the retort *a*, and, of course, in the balloon *b*, it must necessarily ensue that the water of the bottles *c* and *d* would be forced, by the pressure of the atmosphere, into the balloon, and possibly into the retort, which might cause a dangerous explosion; but, with the addition of the central tubes, a sufficient quantity of air rushes through them to supply any accidental vacuum. This inconvenience, however, is still more effectually obviated by Welther's tube of safety (fig. 31, *b*), which supersedes the expediency of three-necked bottles. The apparatus being adjusted, as shown by the figure, a small quantity of water is poured into the funnel, so as to about half fill the ball *b*. When any absorption happens, the fluid rises in the ball, till none remains in the tube, when a quantity of air immediately rushes in and supplies the partial vacuum in *a*. On the other hand, no gas can escape, under ordinary circumstances; because any pressure from within is instantly followed by the formation of a high column of liquid in the perpendicular tube, which resists the egress of gas. This ingenious invention I can recommend, from ample experience of its utility.

Very useful alterations in the construction of Woulfe's apparatus have been contrived also by Mr. Pepys and Mr. Knight. That of the former is shown (fig. 32), where the balloon *b* is surmounted by a vessel *c* accurately ground to it, and furnished with a glass valve, resembling that affixed to Nooth's apparatus for impregnating water with carbonic acid, commonly sold under that name in the glass shops. This valve allows gas to pass freely into the vessel *c*, but prevents the water which *c* contains from falling into the balloon. Mr. Knight's improvement is described, and represented in a plate, in the Philosophical Magazine, vol. xx.*

When a volatile substance is submitted to distillation, it is necessary to prevent the escape of the vapour through the junctures of the vessels; and this is accomplished by the application of LUTES. The most simple method of confining the vapour, it is obvious, would be to connect the places of juncture accurately together by grinding; and accordingly the neck of the retort is sometimes ground to the mouth of the receiver. This, however, adds too much to the expense of apparatus to be generally practised.

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* Another modification of this apparatus, by Dr. Murray, is represented in Nich. Journ. 8vo. vol. iii. or in Murray's System of Chemistry, vol. i. pl. v. fig. 40. Fig. 41 of the same plate exhibits a cheap and simple form of this apparatus, contrived by the late Dr. Hamilton, and depicted originally in his translation of Berthollet on Dyeing. Mr. Burkitt's improvement of this apparatus may be seen in Nicholson's Journal, 4to. vol. v. 349; and an American invention for the same purpose is represented in the Quarterly Journal, viii. 384.

When the distilled liquor has no corrosive property, (such as water, alcohol, ether, &c.) slips of moistened bladder, or of paper, or linen, spread with flour paste, white of egg, or mucilage of gum arabic, sufficiently answer the purpose. The substance which remains, after expressing the oil from bitter almonds, and which is sold under the name of almond-meal, or almond powder, forms a useful lute, when mixed, to the consistency of glazier's putty, with water or mucilage, or, as Mr. Cavendish recommends, with glue, when it requires to be beaten a good deal with a heavy hammer. For confining the vapours of acid, or highly corrosive substances, the *fat lute* is well adapted. It is formed by beating perfectly dry and finely sifted tobacco pipe-clay, with painter's drying oil, to such a consistence that it may be moulded by the hand. The same clay, beat up with as much sand as it will bear, without losing its tenacity, with the addition of cut fibres of tow, or of a little horse-dung, and a proper quantity of water, furnishes a good lute, which has the advantage of resisting a considerable heat, and is applicable in cases where the fat lute would be melted or destroyed. Various other lutes are recommended by chemical writers; but the few that have been enumerated I find to be amply sufficient for every purpose.

On some occasions, it is necessary to protect the retort from too sudden changes of temperature, by a proper coating. For glass retorts, a mixture of moist common clay, or loam, with sand, and cut shreds of tow or flax, or with horse-dung, may be employed. If the distillation be performed by a sand heat, the coating needs not to be applied higher than that part of the retort which is bedded in sand; but if the process be performed in a wind furnace (fig. 63), the whole body of the retort, and that part of the neck also which is exposed to the fire, must be carefully coated. To this kind of distillation, however, earthen retorts are better adapted; and they may be covered with a composition originally recommended by Mr. Willis. Two ounces of borax are to be dissolved in a pint of boiling water, and a sufficient quantity of slaked lime added, to give it the thickness of cream. This is to be applied by a painter's brush, and allowed to dry. Over this a thin paste is afterwards to be applied, formed of slaked lime and common linseed-oil, well mixed and perfectly plastic. In a day or two, the coating will be sufficiently dry to allow the use of the retort.

For joining together the parts of iron vessels, used in distillation, a mixture of the finest China clay, with a solution of borax, is well adapted. In all cases, the different parts of any apparatus made of iron, should be accurately fitted by boring and grinding, and the above lute is to be applied to the part which is received into an aperture. This will generally be sufficient without any exterior luting; otherwise the lute of clay, sand, and flax, already described, may be applied over, as well as within, the joint.

In every instance, where a lute or coating is applied, it is advisable to allow it to dry before the distillation is begun; and even the fat lute, by exposure to the air during one or two days after its application, is much improved in firmness. The clay and sand lute is perfectly useless, except it be previously quite dry. In applying a lute, the part immediately over the juncture should swell outwards, and its diameter should be gradually diminished on each side. (See fig. 13, where the luting is shown, applied to the joining of the retort and receiver.)

Beside the apparatus already described, a variety of vessels and instruments are necessary, having little resemblance to each other, in the purposes to which they are adapted. Glass vessels are required for effecting *solution*, which often requires the application of heat, and sometimes for a considerable duration. In the latter case, it is termed digestion, and the vessel, fig. 4, called a *matrass*, is the most proper for performing it. When solution is required to be quickly effected, the bottle, fig. 5, with a rounded bottom, may be used; or a common Florence oil flask, well cleaned by soap lees, serves the same purpose extremely well, and bears, without cracking, sudden changes of temperature. For *precipitations*, and separating liquids from precipitates, either form of the decanting-jar (fig. 14) will be found useful; or, if preferred, it may be shaped as in fig. 26, *f*. Perhaps the most useful form is the conical, the widest part of the jar being at the bottom (fig. 14), for in this case the precipitate is least apt to adhere to its sides. Liquids, of different specific gravities, are separated by the vessel, fig. 3; the heavier fluid being drawn off through the cock *b*, and air being admitted by the removal of the stopper *a*, to supply its place. Glass rods, of various lengths, and spoons of the same material, or of porcelain, are useful for stirring acid and corrosive liquids; and a stock of cylindrical tubes, of various sizes, is required for occasional purposes. It is necessary also to be provided with a series of glass measures, graduated into drachms, ounces, and pints. The small tube, fig. 15, called *a dropping tube*, which is open at each end, and blown in the middle into a ball, will be found useful in directing a fine stream of water upon the edges of a filter, or any small object. The same purpose may, also, be very conveniently effected by fixing a piece of glass tube of small bore, two or three inches long, and bent at one end to an obtuse angle, into a hole bored in a cork, which may be used as the stopple of an eight ounce vial filled with water, fig. 25, *a*. On inverting the vial, and grasping the bottom part of it, the warmth of the hand expels either a few drops, or a small stream of water, which may be directed upon any minute object. When the flow ceases, it may be renewed, if required, by setting the bottle, for a moment, with its mouth upwards (which admits a fresh supply of cool air), and then proceeding as before.

For the drying of precipitates, and other substances, by a heat not exceeding 212°, a very useful apparatus is sold in London, by the makers of chemical implements. It is represented, supported by the ring of a lamp-stand, by fig. 27. The vessel *a* is of sheet-iron or copper japanned and hard-soldered; *c* is a conical vessel of very thin glass, having a rim, which prevents it, when in its place, from entirely slipping into *a*; and *d* is a moveable ring, which keeps the vessel *c* in its place. When the apparatus is in use, water is poured into *a* about as high as the dotted line; the vessel *c*, containing the substance to be dried, is immersed in the water, and secured by the ring *d*; and the whole apparatus set over an Argand's lamp. The steam escapes by means of the chimney *b*, through which a little hot water may be occasionally poured, to supply the waste by evaporation. By changing the shape of *c* to the segment of a sphere, still retaining the rim, I have found it a most convenient vessel for evaporating fluids. For the purpose of depriving organic substances of water without decomposing them, they may be exposed to a temperature of 212° Fahr. in a vacuum with sulphuric acid. An ingenious apparatus for this purpose, invented by Dr. Prout, is described in the Annals of Philosophy, vol. vi. p. 272; and a simple and useful contrivance for the same purpose, by Mr. Cooper, is described in a subsequent part of this work. (See the chapter "On Vegetable Substances.")

Accurate beams and scales, of various sizes, with corresponding weights, some of which are capable of weighing several pounds, while the smaller size ascertains a minute fraction of a grain, are essential instruments in the chemical laboratory. A simple addition to the balance, known to all philosophical instrument makers, fits it for taking the specific gravities of solids. The method of doing this will be described in Art. 1, of the chapter in vol. ii. "On Chemical Analysis." A balance of great accuracy and sensibility, and at the same time attainable at a moderate expense, has been invented by Captain Kater. It is described in the Quarterly Journal, xi. 280, and xii. 40. Mortars, also, should be at hand, of various materials, such as glass, porcelain, agate, and metal. Wooden stands, too, of various kinds, for supporting receivers, should be provided.* For purposes of this sort, and for occasionally raising to a proper height any article of apparatus, a series of blocks, made of well-seasoned wood, eight inches (or any other number,) square, and respectively eight, four, two, one, and half an inch in thickness, will be found extremely useful; since, by combining them in different ways, thirty-one different heights may be obtained.

The blow-pipe is an instrument of much utility in chemical researches. A small one, invented by Mr. Pepys, with a flat cylindrical box for condensing the vapour of the breath, and for containing caps, to be occasionally applied with apertures of various sizes, is a commodious form;† but the blow-pipe of Gahn is generally employed by those who are most skilful in the use of this instrument. One of a much smaller size, for carrying in a pocket-book, has been contrived by Dr. Wollaston.‡ A blow-pipe, which is supplied with air from a pair of double bellows, worked by the foot (Phil. Mag. xliii. 280), may be applied to purposes that require both hands to be left at liberty, and will be found useful in blowing glass, and in bending tubes. The latter purpose, however, may be accomplished by holding them over an Argand's lamp with double wicks; or in the flame of a spirit-lamp, the wick of which should be of the thickness of a finger. A simple and ingenious apparatus, in which atmospheric air is expelled from a jet by the pressure of a column of water, is described by Mr. Tilley in the 43d vol. of the Philosophical Magazine. Another contrivance of a similar kind, recommended by Dr. Clarke in the Annals of Philosophy, N. S. i. 428, is sold in London under the name of Toft's Blow-pipe, but it appears to me objectionable on account of the room which it occupies. Occasionally, when an intense heat is required, the flame of the blow-pipe, instead of being supported by the mouth or by common air, may be kept up by a stream of oxygen gas, expelled from a bladder or from a gas-holder.[*] The blow-pipe invented by Mr. Brooke consists of a small square box of copper or iron, into which air is forced by a condensing syringe, and from which it is suffered to rush, through a tube of very small aperture, regulated by a stop-cock, against the flame of a lamp or candle.[†] By means of a screw added to the syringe, the receiver may be filled with oxygen gas, or, as will be described hereafter, with a mixture of hydrogen and oxygen gases. Blow-pipes on this construction may be had of the makers of philosophical instruments. The application of the blow-pipe to chemical analysis, and especially to the examination of minerals, may be best learned from the ample and perspicuous directions contained in Berzelius's *Treatise on the Use of the Blow-pipe*, in one vol. 8vo. translated by Mr. Children. In the plates to that work, all the best forms of the instrument are represented.

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* See Aikin's Chem. Dict. pl. iv. fig. 59, *c*.

† See Aikin's Chem. Dict. pl. vii. figs. 71, 72, 73.

‡ It is described in Nich. Journ. xv. 284. See also pl. x. at the end of this volume.

In the course of this work, various other articles of apparatus will be enumerated, in detailing the purposes to which they are adapted, and the principles on which they are constructed. It must be remembered, however, that it is no part of my object to describe every ingenious and complicated invention, which has been employed in the investigation of chemical science; but merely to assist the student in attaining apparatus for general and ordinary purposes. For such purposes, and even for the prosecution of new and important inquiries, very simple means are sufficient; and some of the most interesting chemical facts may be exhibited, and even ascertained, with the aid merely of Florence flasks, of common vials, and of wine glasses. In converting these to the purposes of apparatus, a considerable saving of expense will accrue to the experimentalist; and he will avoid the encumbrance of various instruments, the value of which consists in show, rather than in real utility.

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[*] See a representation of the apparatus for this purpose in the Chemical Conversations, pl. ix.

[†] Thomson's Annals, vii. 367, or Quarterly Journal, i. 65.

SECTION II.

Of the Apparatus for Experiments on the Gases.

For performing the necessary experiments on gases, many articles of apparatus are essential, that have not hitherto been described. It may assist the student in obtaining the necessary instruments, if a few of the most essential be here enumerated. In this place, however, I shall mention such only as are necessary in making a few general experiments on that interesting class of bodies.

The apparatus, required for experiments on gases, consists partly of vessels fitted for containing the materials that afford them, and partly of vessels adapted for the reception of gases, and for submitting them to experiment.

1. For procuring such gases as are producible without a very strong heat, glass bottles, furnished with ground stoppers and bent tubes, are sufficient (plate ii. fig. 18). Of these, several will be required, of different sizes and shapes, adapted to different purposes. If these cannot be procured, a Florence flask, with a cork perforated by a bent glass tube, or even by a leaden pipe, will serve for obtaining some of the gases.

Those gases, that require a red heat for their liberation, may be procured by exposing to that degree of heat the substance capable of affording them, in earthen retorts or tubes; or in a gun barrel, the touch-hole of which has been accurately plugged by an iron pin. To the mouth of the barrel must be affixed a glass tube, bent so as to convey the gases wherever they may be requisite.

A very convenient apparatus, for obtaining such gases as cannot be disengaged without a red heat, is sold at the shops for philosophical apparatus in London. It consists of a cast-iron retort, having a jointed metallic conducting tube fitted to it by grinding; by means of which the gas may be conveyed in any direction, and to any moderate distance. It is represented as placed, when in actual use, between the bars of a common fire-grate (plate ix. fig. 85, *a*, *b*).

2. For receiving the gases, glass jars, of various sizes (figs. 22, 23), are required, some of which should be furnished with necks at the top, fitted with ground stoppers. Others should be provided with brass caps, and screws, for the reception of air-cocks (fig. 22). Of these last (the air-cocks), several will be found necessary; and, to some of them, bladders, or elastic bottles, should be firmly tied, for the purpose of transferring gases. These jars will also be found extremely useful in experiments on the properties and effects of the gases. Some of them should be graduated into cubical inches. It is important that jars used for containing gases should be perfectly free from cracks, through which, even when scarcely perceptible, some of the gases, especially hydrogen, have been found by Doebereiner to escape (Ann. de Ch. et de Phys. xxiv. 332).

To contain these jars, when in use, a vessel will be necessary, capable of holding a few gallons of water. This may either be of wood, if of considerable size; or, if small, of tin, japanned or painted. Plate iv. fig. 41, *ff*, exhibits a section of this apparatus, which has been termed the pneumato-chemical trough, or pneumatic cistern. Its size may vary with that of the jars employed; and, about two or three inches from the top, it should have a shelf, on which the jars may be placed, when filled with air, without the risk of being overset. In this shelf should be a few small holes, to which inverted funnels may be soldered.

Tubes of various forms and sizes, some of them accurately graduated into hundredths, and others into tenths, of a cubic inch, (see Faraday on Manip. § 112,) are quite essential to those who work much on gaseous substances. Beside these, the experimentalist should be furnished with air-funnels (fig. 19), for transferring gases from wide to narrow vessels.

An apparatus, almost indispensable in experiments on this class of bodies, is a GAZOMETER, which enables the chemist to collect and to preserve large quantities of gas, with the aid of only a few pounds of water. In the form of this apparatus there is considerable variety; but, at present, I have no other view than that of explaining its general construction and use. It consists of an outer fixed vessel *d* (plate iv. fig. 35), and an inner moveable one, *c*, both of japanned iron. The latter slides easily up and down within the other, and is suspended by cords passing over pulleys, to which are attached the counterpoises, *ee*. To avoid the encumbrance of a great weight of water, the fixed vessel *d* is made double, or is composed of two cylinders, the inner one of which is closed at the top and at the bottom. The space of only about half an inch is left between the two cylinders, as shown by the dotted lines. In this space the hollow vessel *c* may move freely up and down. The interval is filled with water as high as the top of the inner cylinder. The cup, or rim, at the top of the outer vessel, is to prevent the water from overflowing, when the vessel *c* is forcibly pressed down, in which situation it is placed whenever gas is about to be collected. The gas enters from the vessel in which it is produced, by the communicating pipe *b*, and passes along the perpendicular pipe marked by dotted lines in the centre, into the cavity of the vessel *c*, which continues rising till it is full, when it is stopped by the cross bar to which the pullies are attached.

To transfer the gas, or to apply it to any purpose, the cock *b* is to be shut, and an empty bladder, or bottle of elastic gum, furnished with a stop cock, to be screwed on *a*. When the vessel *c* is pressed down by the hand, the gas passes down the central pipe, which it had before ascended, and its escape at *b* being prevented, it finds its way up a vertical pipe, which is fixed to the outer surface of the vessel, and which is terminated by the cock *a*. By means of an ivory mouth-piece screwed upon this cock, the gas, included in the instrument, may be respired, the nostrils being closed by the fingers. When it is required to transfer the gas into glass jars standing inverted in water, a crooked tube may be employed, one end of which is screwed upon the cock *b*, while the other aperture is brought under the inverted funnel, fixed into the shelf of the pneumatic trough. (See fig. 41, *c*.)

Several alterations have been made in the form of this apparatus, but they are principally such as add merely to its neatness and beauty, and not to its utility; and they render it less easy of explanation. The counterpoises *ee* are now, for example, generally concealed in the framing, and the moveable vessel *c* is frequently made of glass. In some delicate experiments of research, it may be necessary to obtain a current of gas, issuing with an uniform velocity, and under a pressure constantly the same. Such an apparatus was employed by Delaroche and Bérard in their researches into the specific heat of the gases. (Ann. de Chim. lxxxv. 224.) Its principle is explained by M. Biot in his Traité de Physique, tome 1.

When large quantities of gas are required (as at a public lecture), the **gas-holder** (plate iv. fig. 36,) will be found extremely useful. It is made of tinned iron plate, japanned both within and without. Two short pipes, *a* and *c*, terminated by cocks, proceed from its sides, and another, *b*, passes through the middle of the top or cover, to which it is soldered, and reaches within half an inch of the bottom. It will be found convenient also to have an air cock, with a very wide bore, fixed to the funnel at *b*. When gas is to be transferred into this vessel from the gazometer, the vessel is first completely filled with water through the funnel, the cock *a* being left open, and *c* shut. By means of a horizontal pipe, the aperture *a* is connected with *a* of the gazometer. The cock *b* being shut, *a* and *c* are opened, and the vessel *c* of the gazometer (fig. 35,) gently pressed downwards with the hand. The gas then descends from the gazometer till the air-holder is full, which may be known by the water ceasing to escape through the cock *c*. All the cocks are then to be shut, and the vessels disunited. To apply this gas to any purpose, an empty bladder may be screwed on *a*, and water being poured through the funnel *b*, a corresponding quantity of gas is forced into the bladder. By lengthening the pipe *b*, the pressure of a column of water may be added; and the gas being forced through *a* with considerable velocity, may be applied to the purpose of a blow-pipe, &c. &c. The apparatus admits of a variety of modifications. The most useful one appears to me to be that contrived by Mr. Pepys, consisting chiefly in the addition of a shallow cistern (*e*, plate ix. fig. 85,) to the top of the air-holder, and of a glass register tube, *f*. which shows the height of the water, and consequently the quantity of gas, in the vessel. A more minute account of it will be given in the description of the ninth plate.*

The gazometer, already described, is fitted only for the reception of gases that are confinable by water; because quicksilver would act on the tinning and solder of the vessel, and would not only be spoiled itself, but would destroy the apparatus. Yet an instrument of this kind, in which mercury can be employed, is peculiarly desirable, on account of the great weight of that fluid, which makes the employment of large quantities of it both inconvenient and costly; and two varieties of the mercurial gazometer have therefore been invented. The one, of glass, is the contrivance of Mr. Clayfield, and is represented in the plate prefixed to Sir H. Davy's 8vo. vol. of Researches, published in 1800. In the other, invented by Mr. Pepys, the cistern for the mercury is of cast iron. A drawing and description of it may be found in the 5th vol. of the Philosophical Magazine; but, as neither of these instruments are essential to the chemical student, and as they are required only in experiments of research, I deem it sufficient to refer to the minute descriptions of their respective inventors. Mr. Newman has lately joined a gazometer of this kind to an improved and most useful mercurial trough, by means of which the advantages of both are obtained with only 60 or 70 pounds of quicksilver. A description and drawing of this apparatus is given in the Quarterly Journal of Science, i. 186. (See also pl. x., and the Description of the Plates, at the end of this volume.)

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* Descriptions and figures of improved gas-holders may be seen also in the 13th, 24th, 27th, and 44th vols. of the Philosophical Magazine.

For these gases that are absorbed by water, a mercurial trough is necessary. For the mere exhibition of a few experiments on these condensable gases, a small wooden trough, eleven inches long, two wide, and two deep, cut out of a solid block of mahogany, is sufficient; but, for experiments of research, one of cast iron, of considerable size, is required. (See plate iii. fig. 31, *f*, *f*.)

The apparatus, required *for submitting gases to the action of electricity*, is shown in plate ix. fig. 84, where *a* represents the nob of the prime conductor of an electrical machine; *b* a Leyden jar, the ball of which is in contact with it, as when in the act of charging; and *c* the tube standing inverted in mercury, and partly filled with gas. The mercury is contained in a strong wooden box *d*, to which is screwed the upright iron pillar *e*, with a sliding collar for securing the tube *c* in a perpendicular position. When the jar *b* is charged to a certain intensity, it discharges itself between the nob *a* and the small ball *i*, which, with the wire connected with it, may be occasionally fitted on the top of the tube *c*. The strength of the shocks is regulated by the distance between *a* and *i*. By the same apparatus, inflammable mixtures of gases may be exploded by electricity. In this case, however, the jar *b* is unnecessary, a spark received by *i* from *a* being sufficient to kindle the mixture.

The method of *weighing gases* is very simple, and easily practised. For this purpose, however, it is necessary to be provided with a good air-pump, and with a globe or flask, furnished with a brass cap and air-cock, as shown fig. 22, *b*. A graduated receiver is also required, to which an air-cock is adapted, as shown at fig. 22, *a*.

Supposing the receiver *a* to be filled with any gas, the weight of which is to be ascertained, we screw the cock of the vessel *b* on the transfer plate of an air-pump, and exhaust it as completely as possible. The weight of the exhausted vessel is then very accurately taken, even to a small fraction of a grain, and it is screwed upon the air-cock of the receiver *a*. On opening both cocks, the last of which should be turned very gradually, the gas ascends from the vessel *a*, and the quantity which enters into the flask is known by the graduated scale on *a*. On weighing the vessel a second time, we ascertain how many grains have been admitted. If we have operated on common air, we shall find its weight to be at the rate of about 30.5 or 31 grains to 100 cubical inches. The same quantity of oxygen gas will weigh about 34 grains, and of carbonic acid gas upwards of 47 grains

In experiments of this kind it is necessary either to operate with the barometer at 30 inches, and the thermometer at 60° Fahrenheit, or to reduce the volume of gas employed to that pressure and temperature, by rules which will presently be given. Great care is to be taken, also, not to warm any of the vessels by contact with the hands, from which they should be defended by a glove. On opening the communication between the receiver and the exhausted globe, if any water be lodged in the air-cock attached to the former, it will be forcibly driven into the globe, and the experiment will be frustrated. This may be avoided by using great care in filling the receiver with water, before passing into it the gas under examination.

The specific gravity of any gas compared with common air is readily known, when we have once determined its absolute weight. Thus, if 100 cubic inches of air weigh 30.5 grains, and the same quantity of oxygen gas weighs 34 grains, we say,

$$30.5 : 34 :: 1.000 : 1.1147.$$

The specific gravity of oxygen gas will therefore be as 1.1147 to 1.000. We may determine, also, the specific gravity of gases, more simply, by weighing the flask, first when full of common air, and again when exhausted; and afterwards by admitting into it as much of the gas under examination as it will receive; and weighing it a third time. Now, as the loss between the first and second weighing is to the gain of weight on admitting the gas, so is common air to the gas whose specific gravity we are estimating. Supposing, for example, that by exhausting the flask it loses 30.5 grains, and that, by admitting carbonic acid, it gains 47; then

$$30.5 : 47 :: 1.000 : 1.5409.$$

The specific gravity of carbonic acid is therefore 1.5409, air being taken at 1.000. And, knowing its specific gravity, we can, without any farther experiment, determine the weight of 100 cubic inches of carbonic acid; for as the specific gravity of air is to that of carbonic acid, so is 30.5 (or any other more accurate weight of 100 inches of air) to the number required; or

$$1.000 : 1.5409 :: 30.5 : 47.$$

One hundred inches of carbonic acid, therefore, will weigh 47 grains.

Previously to undertaking experiments on other gases, it may be well for an unpractised experimentalist to acquire manual dexterity by transferring common air from one vessel to others of different sizes, in the following manner:

1. When a glass jar, closed at one end, is filled with water, and

held with its mouth downwards, in however small a quantity of water, the fluid is retained in its place by the pressure of the atmosphere on the surface of the exterior water. Fill in this manner, and invert, on the shelf of the pneumatic trough, one of the jars, which is furnished with a stopper (fig. 23.). The water will remain in the jar so long as the stopper is closed; but immediately on removing it, the water will descend to the same level within as without; for it is now pressed equally upwards and downwards by the atmosphere, and falls therefore in consequence of its own gravity.

2. Place the jar, filled with water and inverted, over one of the funnels of the shelf of the pneumatic trough. Then take another jar, filled (as it will be of course) with atmospherical air. Place the latter with its mouth on the surface of the water; and, on pressing it in the same position below the surface, the included air will remain in its situation. Bring the mouth of the jar beneath the funnel in the shelf, and incline it gradually. The air will now rise in bubbles, through the funnel, into the upper jar, and will expel the water from it into the trough.

3. Let one of the jars, provided with a stop-cock at the top, be placed full of air on the shelf of the trough. Screw upon it an empty bladder; open the communication between the jar and the bladder, and press the former into the water. The air will then pass into the bladder till it is filled; and, when the bladder is removed from the jar, and a pipe screwed upon it, the air may be again transferred into a jar inverted in water.

For the purpose of transferring gases from a wide vessel standing over water, into a small tube filled with and inverted over mercury, I have long used the following simple contrivance of Mr. Cavendish. A tube, eight or ten inches long, and of very small diameter, is drawn out to a fine bore, and bent at this end, so as to resemble the italic letter *l*. The point is then immersed in quicksilver, which is drawn into the tube till it is filled, by the action of the mouth. Placing the finger over the aperture at the straight end, the tube filled with quicksilver is next conveyed through the water, with the bent end uppermost, into an inverted jar of gas. When the finger is removed, the quicksilver falls from the tube into the trough, or into a cup placed to receive it, and the tube is filled with the gas. The whole of the quicksilver, however, must not be allowed to escape; but a column must be left, a few inches long, and must be kept in its place by the finger. Remove the tube from the water; let an assistant dry it with a towel or with blotting paper; and introduce the point of the bent end into the aperture of the tube standing over quicksilver. On withdrawing the finger from that aperture which is now uppermost, the pressure of the column of quicksilver, added to the weight of the atmosphere, will force the gas from the bent tube into the one standing in the mercurial trough.

On every occasion, when it is necessary to observe the precise quantity of gas, at the commencement and close of an experiment, it is essential that the barometer and thermometer should exactly correspond at both periods. An increased temperature, or a fall of the barometer, augments the apparent quantity of gas; and a reduced temperature, or a higher barometer, diminishes its bulk. Another circumstance, an attention to which is indispensable in all accurate experiments, is that the surface of the fluid, by which the gas is confined, should be precisely at the same level within and without the jar. If the fluid be higher within the jar, the contained gas will be under a less pressure than that of the atmosphere, the weight of which is counterpoised by that of the column of fluid within. In mercury, this source of error is of very considerable amount; as any person may be satisfied by raising, above the surface of the quicksilver of a trough, a tube partly filled with that fluid, and partly with air, for the volume of the air will enlarge as the surface of the mercury within the tube is elevated above the outer surface.

In experiments on gases, it is not always possible to begin and conclude an experiment at precisely the same temperature, or with the same height of the barometer; or even to bring the mercury within and without the receiver to the same level. In these cases, therefore, calculation becomes necessary; and, with the view of comparing results more readily and accurately, it is usual to reduce quantities of gas to the bulk they would occupy under a given pressure, and at a given temperature. In this country, it is now customary to assume as a standard 30 inches of the barometer, and 60° of Fahrenheit's thermometer, and to bring to these standards observations made under other degrees of atmospheric pressure and temperature. The rules for these corrections, which are sufficiently simple, are the following:—

Rules for reducing the Volume of Gases to a mean Height of the Barometer, and mean Temperature.

1. *From the space, occupied by any quantity of gas under an observed degree of pressure, to infer what its volume would be under the mean height of the barometer, taking this at 30 inches, as is now most usual.*

This is done by the rule of proportion; for, as the mean height is to the observed height, so is the observed volume to the volume required. For example, if we wish to know what space would be filled, under a pressure of 30 inches of mercury, by a quantity of gas, which fills 100 inches, when the barometer is at 29 inches,

30 : 29 : : 100 : 96.66.

The 100 inches would, therefore, be reduced to 96.66.

2. *To estimate what would be the volume of a portion of gas, if brought to any required temperature.*

If the temperature of the gas is above 32° Fahrt. multiply its total volume by 480, and divide the product by 480 *plus* the number of degrees that the temperature of the gas exceeds 32° Fahrenheit. By this process, we obtain the space that the gas would occupy at 32° Fahrenheit.

To determine its volume at any other temperature, add $\frac{1}{480}$ of the volume at 32° for each degree that the temperature required exceeds 32° Fahrenheit.

Thus, to find what space 100 cubic inches of gas at 50° would occupy if raised to 60, $\frac{100 \times 480}{480+18} = 96.4 =$ the volume at 32°.

And $96.4 + \frac{96.4 \times 28}{480} = 102$, the volume at 60°.

3. In some cases, it is necessary to make a double correction, or *to bring the gas to a mean both of the barometer and thermometer.* We must then first correct the temperature, and afterwards the pressure. Thus to know what space 100 inches of gas at 50° Fahrenheit, and 29 inches barometer, would fill at 60° Fahrenheit and 30 inches barometer, we first convert the 100 inches, by the second process, to 102. Then by the first,

30 : 29 : : 102 : 98.6.

Or 100 inches thus corrected, would be only 98.6.

4. *To ascertain what would be the absolute weight of a given volume of gas at a mean temperature, from the known weight of an equal volume at any other temperature;* first, find by the second process what would be its bulk at a mean temperature; and then say, as the corrected bulk is to the actual weight, so is the observed bulk to the number required. Thus if we have 100 cubic inches of gas weighing 50 grains at 50° Fahrenheit, if the temperature were raised to 60°, they would expand to 102. And

102 : 50 : : 100 : 49.02.

Therefore 100 inches of the same gas at 60° would weigh 49.02 grains.

5. *To learn the absolute weight of a given volume of gas under a mean pressure, from its known weight under an observed pressure,* say, as the observed pressure is to the mean pressure, so is the observed weight to the corrected weight. For example, having 100 inches of gas which weigh 50 grains under a pressure of 29 inches, to know what 100 inches of the same gas would weigh, the barometer being 30 inches,

29 : 30 : : 50 : 51.72.

Then 100 inches of the same gas, under 30 inches pressure, would weigh 51.72 grains.

6. In some cases it is necessary to combine the two last calculations. Thus, if 100 inches of gas at 50° Fahrenheit, and under 29 inches pressure, weigh 50 grains, to find what would be the weight of 100 inches at 60° Fahrenheit, and under 30 inches of the barometer, first correct the temperature, which reduces the weight to 49.02 grains. Then,

29 : 30 : : 49.02 : 50.71.

One hundred inches, therefore, would weigh 50.71 grains.

Corrections for Moisture in Gases.

Another correction, which it is often necessary to make in taking the weight of gases, is for the quantity of aqueous vapour diffused through them. It is obvious that all gases, which are specifically heavier than aqueous vapour, must have their specific gravity diminished by admixture with steam; and, on the contrary, all gases that are specifically lighter than steam must have their specific gravity increased by that admixture. For the following formulæ, I am indebted to Mr. Dalton, who has obligingly stated them at my request.

“ At ordinary temperatures, the tension or elasticity of aqueous vapour varies from $\frac{1}{100}$ to $\frac{1}{10}$ of the whole atmospheric pressure; in the present case, it is supposed to be a given quantity. The specific gravity of pure steam compared with that of common air, under like circumstances of temperature and pressure, is, according to Gay Lussac, as 0.620 to 1.

Let a = weight of 100 cubic inches of dry common air, at the pressure 30 inches and temperature 60° Fahrenheit; p = any variable pressure of atmospheric air; and f = pressure or tension of vapour in any moist gas. Then the following formulæ will be found useful in calculating the volumes, weights, and specific gravities of dry and moist gases; putting M for the volume of moist gas; D for that of dry gas; and V for that of vapour: all of the same pressure and temperature.

1. $M = D + V$.
2. $\frac{p-f}{p} M = D$.
3. $\frac{f}{p} M = V$.
4. $M = \frac{p\,D}{p-f} = \frac{p\,V}{f}$.

If we wish to infer the specific gravity of any dry gas from the observed specific gravity or weight of the same mixed with vapour, it will be convenient to expound p by that particular value which corresponds with a, namely 30 inches of mercury; and let s = the specific gravity of the dry gas, and w = the observed weight of 100 cubic inches of the moist gas.

Then we shall have the following, viz.

5. $\frac{30-f}{30} .\ s\,a + \frac{f}{p} \times .620\,a = w$.
6. $s = \frac{30}{30 - f\,a} \left(w - \frac{f}{p} \times .620\,a.\right)$

Exemplifications.

1. 98 vol. dry air + 2 vol. vapour = 100 vol. of moist air.
2. Given $p = 30$, $f = .5$, and $M = 100$.

Then $\frac{p-f}{p} . M = D$, the dry air, $= 98\frac{1}{3}$.

3. And $\frac{f}{p} M = V$, the vapour, $= 1\frac{2}{3}$.
4. Given $D = 100$, $p = 30$, $f = .4$.

Then $\frac{30 \times 100}{29.6} = 101.35$, the moist air.

Given V[*] $= 2$, $p = 30$, $f = .3$.

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[*] It is easy to see that V, in this and the other cases, mostly will denote a virtual volume only; or such as would result, if the vapour were condensable like a gas, without being convertible into a liquid.

Then $\frac{30 \times 2}{.3} = 200$, the moist air.

5. Let $f = .5$, $s = 1.111$, $a = 30.5$, $p = 29.5$,

Then $\frac{30 - .5}{30}\ 1.111 \times 30.5 + \frac{.5}{29.5} \times .62 \times 30.5 = 33.64 = w$, which gives the specific gravity 1.103.

6. Let f, a, and p as above, and $w = 2.5$, corresponding to sp. gr. 0.8197.

Then $s = \frac{30}{29.5 \times 30.5}\left(2.5 - \frac{.5}{29.5} \times .62 \times 30.5\right) = .07266.$

The above formulæ apply equally well if V be a permanent gas, or any other vapour beside that of water, the specific gravity of the gas or vapour being substituted instead of .620, that of steam."

The correction respecting gases, most frequently required in the laboratory, is for moisture; for it is scarcely possible to obtain any gas, artificially deprived of aqueous vapour, in quantity sufficient to be weighed in that state. It is better, therefore, to weigh the gas charged with the full quantity of moisture due to its temperature, which it will soon be, if allowed to remain in contact with water; and then to calculate what would be the weight of the same volume, entirely free from aqueous vapour. This may be done by the following rule, in exemplifying which 100 cubic inches of moist atmospheric air, at 60 Fahr. and 30 bar., are assumed to weigh 31 grains. Find the force of vapour at that temperature by Mr. Dalton's table, which is 0.524.

Then 30 : 0.524 : : 100 : 1.747 = the volume of aqueous vapour in 100 inches of moist air at 60°.

And as 100 cub. in. of aqueous vapour weigh 19 grains, 1.747 cub. in. must weigh 0.3368 grain.

Next from the weight of 100 cub. in. moist air - 31.
Subtract - - - - - - - - - - 0.3368

30.6632

We have then the weight of 100 — 1.747 = 98.253 cub. in. dry air, viz. 30.6632 grains.

And 98.253 : 30.6632 : : 100 : 31.214.

The weight, then, of 100 cub. in. dry air, at 30 inches bar. and 60° Fahr. is 31.214 grains.

The specific gravity of any other gas compared with common air is then easily determined. For as the weight of 100 cub. in. of dry common air (whether 30.5 or 31 gr. is not yet decided), is to the weight of 100 cub. in. of any other dry gas, so is unity to the number required.

In the Appendix, vol. ii. the reader will find two tables, copied from the second volume of Mr. Dalton's New System of Chemical Philosophy, which will render these corrections still more easy, and more generally applicable.

CHAPTER II.

OF CHEMICAL AFFINITY.

All bodies, composing the material system of the universe, have a natural tendency to approach each other, whatsoever may be the distances at which they are placed. The operation of this force extends to the remotest parts of the planetary system, and is one of the causes that preserve the regularity of their orbits. The smaller bodies, also, that are under our more immediate observation, are influenced by the same power, and fall to the Earth's surface, when not prevented by the interference of other forces. From these facts, the existence of a property has been inferred, which has been called *attraction*, or, more specifically, the *attraction of gravitation*. Its nature is entirely unknown to us; but some of its laws have been investigated, and successfully applied to the explanation of phenomena. Of these, the most important are, that the force of gravity acts on bodies directly in proportion to the quantity of matter in each; and that it decreases in the reciprocal proportion of the squares of the distances.

From viewing bodies in the aggregate, we may next proceed to contemplate them as composed of minute particles. These particles, it is probable, consist of solids, which are incapable of mechanical division, but are still possessed of the dimensions of length, breadth, and thickness. In simple bodies, the particles must be all of the same nature, or *homogeneous*. In compound bodies, we are to understand, by the term *particles*, the smallest parts into which bodies can be resolved without decomposition. The word *atom* has of late been revived, to denote both these kinds of particles; and we may, therefore, speak with propriety of *simple atoms* and of *compound atoms*. When two atoms of different kinds unite to form a third or compound atom, we may term the two first *component atoms*; and, if these have not been decomposed, they may be called *elementary* or *primary atoms*.

The atoms or particles of bodies are also influenced by the force of attraction, but not unless when placed in *apparent* contact. Hence a distinction has been made between gravitation, and that kind of attraction which is effective only at insensible distances. The latter has been called *contiguous attraction*; and it has been distinguished, as it is exerted between particles of matter of the *same* kind, or between particles of a *different* kind.

By the *attraction of aggregation*, the *cohesive attraction*, or more simply *cohesion*, is to be understood that force or power, by which particles or atoms of matter *of the same kind* attract each other, the only effect of this attraction being an aggregate or mass. Thus a lump of copper may be considered as composed of an infinite number of minute particles or integrant parts, each of which has precisely the same properties as those that belong to the whole mass. These are united by the force of cohesion. But if the copper be combined with another metal (such as zinc), we obtain a compound (brass), the constituent parts of which, copper and zinc, are combined by the power of *chemical affinity;* a term which it is proper to restrict to the attraction existing between particles of *different* kinds. In simple bodies, therefore, cohesion is the only force exerted between their particles. But in compound bodies, we may distinguish the force, with which the *primary* or *component* atoms are united, from that which the *compound* atoms exert towards each other; the former being united by chemical affinity, and the latter by the cohesive attraction.

SECTION I.

Of Cohesion, Solution, and Crystallization.

The cohesive attraction is a property, which is common to a great variety of bodies. It is most strongly exerted in solids; and in these it is proportionate to the mechanical force required for effecting their disunion. In liquids, it acts with considerably less energy; and in aëriform bodies we have no evidence that it exists at all; for their particles, as will afterwards be shown, are mutually repulsive, and, if not held together by pressure, separate to great distances. The force of this attraction is not only different among different bodies, but in various states of the same body. Thus in the cohesion of certain metals (steel for instance), important changes are produced by the rate of cooling, by hammering, and by other mechanical operations. Water, also, in a solid state, has considerable cohesion, which is much diminished when it becomes liquid, and is entirely destroyed when it is changed into vapour.

The most important view, in which the chemist has to consider cohesion, is that of a force either counteracting or modifying chemical affinity; for the more strongly the particles of any body are united by this power, the less are they disposed to enter into combination with other bodies. In many cases, a very powerful affinity existing between two substances may be rendered wholly inefficient, by the strong cohesion of one or both of them. Hence it has been received as an axiom, that *the affinity of composition is inversely proportionate to the cohesive attraction.* To the language, however, in which this axiom is expressed, it has been justly objected, that it implies an accuracy of proportion between the forces of cohesion and chemical affinity, which cannot be proved to exist; since all that can truly be affirmed is, in general terms, that the affinity of composition is less effective, as the attraction of cohesion is stronger.

The cohesion of bodies may be overcome, 1st, by mechanical operations, as by rasping, grinding, pulverizing, and other modes of division, which are generally employed as preliminary steps to chemical processes. In some instances, even a minuter division of bodies is necessary, than can be accomplished by mechanical means; and recourse is then had to precipitation. Silica, for example, in the state of rock crystal, may be boiled for a long time in liquid potassa, without any appearance of chemical action. It may even be bruised to the finest powder, without being rendered sensibly soluble. But when first precipitated from a state of chemical solution, it is readily dissolved by that menstruum, and even by some weak acids.

2dly. Cohesion may be counteracted by heat, applied so as to melt one or both of the bodies, if fusible; or to raise them into vapour, if volatile. Lead and sulphur contract no union, till one or both of them are melted by heat. Arsenic and sulphur are united most effectually, by bringing them into contact, when both are in a state of vapour.

3dly. Cohesion may be counteracted by *solution;* and this is so general a condition of chemical union, that it was formerly received as an axiom, that *bodies do not act on each other, unless one or both are in a state of solution;* a principle, to which the progress of chemical science has since discovered many exceptions.

The term *solution* is applied to a very extensive class of phenomena. When a solid disappears in a liquid, if the compound exhibit perfect transparency, we have an example of solution. The expression is applied, both to the *act* of combination, and to the *result* of the process. When common salt, such as is used in cookery, is agitated with water, it disappears; in other words, its solution takes place; and we also term the liquid which is obtained, *a solution of salt in water.* This is one of the simplest cases that can be adduced, of the efficiency of chemical affinity: for solution is always the result of an affinity between the fluid and the solid which is acted upon, often feeble it is true, yet sufficient in force to overcome the cohesion of the solid. This affinity continues to act, until, at length, a certain point is attained, where the affinity of the solid and fluid for each other is balanced by the cohesion of the solid, and the solution cannot be carried farther. This point is called *saturation,* and the fluid obtained is termed a *saturated solution.*

With respect to common salt, water acquires no increase of its solvent power by the application of heat. But there are various salts with which water, though saturated at the common temperature of the atmosphere, is yet capable of dissolving a further quantity by an increase of its temperature. When a solution, thus charged with an additional quantity of salt, is allowed to cool, the second portion of salt is deposited in a form resembling its original one. In a few instances, the solvent power of water is diminished by raising its temperature. Of this, an example is furnished by quicklime, which dissolves more abundantly in cold than in hot water. Some salts, also, have the property of dissolving most abundantly in water of a certain temperature, and of being less soluble either above or below that temperature. Such are the sulphate and seleniate of soda. (35 Ann. de Ch. et de Phys. 102.)

To recover a salt from its solution, if its solubility does not vary with the temperature of the solvent, as in the instance of common salt, it is necessary to expel a portion of the fluid by heat. This constitutes the process of *evaporation*. If the evaporation be carried on very slowly, so that the particles of the solid may approach each other in the way best adapted to them, we obtain solid figures, of a regular shape, called *crystals*. The crystallization of a solid may also take place from that state of fluidity which is produced by heat. Thus several of the metals crystallize on cooling from a melted state; and some volatile bodies, as arsenic, assume, when condensed from the state of vapour, the shape of regular crystals.

In the act of separating from the water in which they were dissolved, the crystals of almost all salts carry with them a quantity of water, which is essential to the regularity of their form, and cannot be expelled without reducing them to shapeless masses. It is termed their *water of crystallization*. Its proportion varies in different salts; in some it is extremely small; in others it constitutes the principal part of the salt, and is even so abundant, as to liquefy them on the application of heat, producing what is called the *watery fusion*. In every salt it exists, not in an uncertain but in a definite proportion, bearing in the same salt the same ratio to the solid saline matter, but differing for different salts. The water of crystallization is retained also in different salts with very different degrees of force. Some crystals, which lose their watery ingredient by mere exposure to the atmosphere, are said to *effloresce*. In some, the loss is so complete that they become quite *anhydrous*; but others retain variable quantities of water, according to the hygrometric state of the air. (Ann. de Ch. et de Ph. xxxii. 334.). Other salts, on the contrary, not only hold their water of crystallization very strongly, but even attract more; and, on exposure to the atmosphere, become liquid, or *deliquiate*. The property itself is called *deliquescence*. There are, however, a few salts (as sulphate of potassa and chloride of sodium) which, though their forms are perfectly regular, contain essentially no water of crystallization, but yet hold a very small portion, mechanically retained between the plates of their crystals.

When two salts are contained in the same solution, which vary in their degree of solubility, and which have no remarkable attraction for each other, they may be obtained separate. For by carefully reducing the quantity of the solvent by evaporation, the salt whose particles have the greatest cohesion, will crystallize first. If both salts are more soluble in hot than in cold water, the crystals will not appear till the liquid cools. But if one of them, like common salt, is equally soluble in hot and in cold water, crystals will appear, even during the act of evaporation. In this way we may separate nitre from common salt, the crystals of the latter being formed during evaporation; while those of nitre do not appear till some time after the fluid has cooled.

Salts, which are deposited in regular shapes, generally adhere to the surface of the vessel containing the solution, or to any substance, such as pieces of thread or of wood, introduced for the purpose of collecting them. But a still more effectual way of inducing crystallization is to immerse, in the solution, a crystal of the same kind with that which we expect to be formed. The crystal, thus exposed, receives successive additions to its several surfaces, and preserves its form, with a considerable addition to its magnitude. This curious fact was originally noticed by Le Blanc, who has founded on it a method of obtaining large and perfect crystals.

In some instances, the affinity of a salt for its solvent is so powerful, that it will not separate from it in the form of crystals; but will yet crystallize from another fluid, which is capable of dissolving it, and for which it has a weaker affinity. Potassa, for instance, cannot be made to crystallize from its watery solution, but will yet separate, in a regular form, from its solution in alcohol.

To clear away from any crystalline product, the *mother water*, as the remaining fluid has been called, Robiquet recommends the transmission, by suction, of a current of air through the crystals. The simplest way of doing this, is to place the crystals in a glass funnel, the pipe of which is loosely stopped by a little cotton wool, and then fixed in one of the mouths of a two-necked bottle, the juncture being made as nearly air-tight as possible. A bent tube being also fixed tightly into the other neck, and the air sucked through this tube, the crystals are cleaned in a few seconds. (Ann. of Phil. N. S. xii. 460.)

Every solid, that is susceptible of crystallization, has a tendency to assume a peculiar shape. Thus common salt, when most perfectly crystallized, forms regular cubes; nitre has the shape of a six-sided prism; and alum that of an octahedron. It has, indeed, been alleged, as an objection to the received theory of crystallization, that minerals, differing essentially in their composition, have precisely the same primitive form. For example, the primitive form of carbonate of lime, and of the compound carbonate of lime and magnesia, is, in both, a regular rhomboid, so nearly resembling each other, as to have been supposed to be precisely the same. In this case, however, Dr. Wollaston has shown, that though the figures are similar, yet their angles, on admeasurement by a nice instrument, differ very appreciably. (Phil. Trans. 1812.) But other instances have been since brought forward by M. Beudant, in which artificial salts, composed of *dissimilar* ingredients, have *the same* crystalline form; and Dr. Wollaston has satisfied himself of the accuracy of M. Beudant's remark, that the mixed sulphates of copper and iron, of zinc and iron, and of copper, zinc, and iron, assume forms, in which no difference has yet been discovered from that of simple sulphate of iron alone.* He apprehends, indeed, that on minute investigation, some difference will be found, either in the angles or linear measures of those different salts; but till this has been established, the facts, as they stand, must be acknowledged to be exceptions to the principle, that *identity of crystalline form is necessarily connected with identity of chemical composition.* In the instances which have been given, the perfect transparency of the crystals forbids our considering them as an intermixture of foreign matter grouped together by sulphate of iron; and this explanation is, also, irreconcilable with the fact, discovered by Dr. Wollaston, that a mixed solution of sulphates of zinc and copper, in certain proportions, affords crystals which, though containing no iron, still agree so nearly in form with those of sulphate of iron, that he could not undertake to point out any difference between them. In illustration, also, of the principle, that the same salt assumes different fundamental or *primitive* forms, according to the nature of the liquid in which the crystals have been formed, Wöllner asserts, that when a small portion of solution of sulphate of iron is poured into a solution of alum, and the whole allowed to crystallize, the sulphate of iron assumes the octahedral form of the alum, though these octahedral crystals afford scarcely a trace of the aluminous salt. (Quart. Journ. xxii. 199.)

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* Tompson's Annals, xi. 262, 283, xiii. 126. See also Mitscherlich; Ann. de Chim. et Phys. xiv. 172, 326.

We are indebted to Professor Mitscherlich of Berlin for a series of essays, published in the 19th, 32d, and 37th volumes of the *Annales de Chimie et de Physique*, which open new views of the causes that influence the molecular arrangement of crystals. A close connexion, he has shown, exists between crystalline form and atomic constitution. Identity of form he finds to be determined by the *number of atoms*, independently of the chemical nature of the elements. Certain different elements, combined with the same number of one or more elements, affect the same crystalline forms; and in this respect the chemical elements may be classed together in groups. Elements belonging to the same group he calls *isomorphous;* for example, in the phosphates and arseniates, the sulphates and seleniates, we have, along with identity of form, an exact analogy as to the number of atoms of base, acid, and water, constituting these salts, and of consequence *isomorphism*. In the course of his inquiries, Mitscherlich observed several curious facts, respecting the influence of the temperature of solutions on the form of salts deposited from them; and in salts completely formed, he first remarked that a change in the position of their molecules may be produced by causes which do not produce fluidity, or any alteration of chemical constitution. (Ann. de Ch. Feb. 1828.) The subject has been pursued also by Mr. Haidinger, in an ingenious paper published in the Transactions of the Royal Society of Edinburgh (1827), and by Mitscherlich himself, in a memoir on the crystalline form and composition of the sulphates, seleniates, and chromates. (Ann. de Ch. et de Ph. May, 1828.)

It has been long known that the same solid admits of great varieties of crystalline figure, without any variation of its chemical composition. Calcareous spar, for example, appears in six-sided prisms, in three or six-sided pyramids, and in more than three hundred other shapes. These varieties, occasioned by accidental circumstances, which modify the operation of the force of cohesion, are found, upon a careful examination and comparison, to be reducible to a small number of simple figures, which, for each individual species, is always the same.

The attempt to trace all the observed forms of crystals to a few simple or primary ones, seems to have originated with Bergman. (See his Essays, vol. ii.) In the instance of calcareous spar, this distinguished chemist demonstrated that its numerous modifications may possibly result from one simple figure, the rhomb, by the accumulation of which, in various ways, crystals of the most opposite forms may be generated. This theory he extended to crystals of every kind; and he accounted for the differences of their external figures, by varieties of their mechanical elements or minute molecules.

About the same period with Bergman, or immediately afterwards, M. Romé de l'Isle pursued still farther the theory of the structure of crystals. He reduced the study of crystallography to principles more exact, and more consistent with observation. He classed together, as much as he was able, crystals of the same nature. From among the different forms belonging to the same species he selected, for the primitive form, one which appeared to him to be the most proper, on account of its simplicity. Supposing this to be truncated in different manners, he deduced the other forms, and established a certain gradation, or series of passages, from the primitive form to complicated figures, which, on first view, would scarcely appear to have any connexion with it. To the descriptions and figures of the primitive forms, he added the mechanical measurement of the principal angles, and showed that these angles are constantly the same in each variety. It must be acknowledged, however, that the primitive forms, assumed by this philosopher, were entirely imaginary, and not the result of any experimental analysis. His method was to frame an hypothesis; and then to examine its coincidence with actual appearances. On his principles, any form might have been the primitive one, and any other have been deduced from it.

It was reserved for the sagacity of the Abbé Haüy to unfold the true theory of the structure of crystals, and to support it both by experimental and mathematical evidence. By the mechanical division of a complicated crystal, he first obtained the simple form, and afterwards constructed, by the varied accumulation of the primitive figure, according to mathematical synthesis, all the observed varieties of that species.

Every crystal may be divided by means of proper instruments; and, if split in certain directions, presents plane and smooth surfaces. If split in other directions, the fracture is rugged, is the mere effect of violence, and is not guided by the natural joining of the crystal. This fact had been long known to jewellers and lapidaries; and an accidental observation of it proved, to the Abbé Haüy, the key of the whole theory of crystallization. By the skilful division of a six-sided prism of calcareous spar, he reduced it to a rhomb, precisely resembling that which is known under the name of Iceland crystal. Other forms of calcareous spar were subjected to the same operation; and, however different at the outset, finally agreed in yielding, as the last product, a rhomboidal solid. It was discovered also by Haüy, that if we take a crystal of another kind (the cubic fluor spar for instance), the nucleus, obtained by its mechanical division, will have a different figure, *viz.*, an octahedron. Other crystallized bodies produce still different forms; which are not, however, very numerous. Those which have hitherto been discovered, are reducible to six; the parallelopipedon, which includes the cube, the rhomb, and all the solids which are terminated by six faces, parallel two and two; the tetrahedron; the octahedron; the regular hexahedral prism; the dodecahedron with equal and similar rhomboidal planes; and the dodecahedron with triangular planes.

The solid of the primitive form, or nucleus of a crystal, obtained by mechanical division, may be subdivided in a direction parallel to its different faces. All the sections thus produced being similar, the resulting solids are precisely similar in shape to the nucleus, and differ from it only in size, which continues to decrease as the division is carried farther. To this division, however, there must be a limit, beyond which we should come to particles so small, that they could no longer be divided. At this term, therefore, we must stop; and to these last particles, the result of an analysis of the primitive nucleus, and similar to it in shape, Haüy has given the name of the *integrant molecule*. If the division of the nucleus can be carried on in other directions than parallel to its faces, the integral molecule may then have a figure different from that of the nucleus. The forms, however, of the integrant molecule, which have hitherto been discovered, are only three: the tetrahedron, the simplest of pyramids; the triangular prism, the simplest of prisms; and the parallelopipedon, including the cube and rhomboid, the simplest of solids which have their faces parallel two and two. With respect to octahedral crystals, there is a difficulty, whether the octahedron, or tetrahedron, is to be adopted as the primitive form; and, whichsoever be chosen, since neither of them can fill space without leaving vacuities, it is not easy to conceive any arrangement by which the particles will remain at rest. To obviate this difficulty, Dr. Wollaston has suggested that, in such instances, the elementary particles may be perfect spheres; and, by the due application of spheres to each other, he has shown, that a variety of crystalline forms may be produced; *viz.*, the octahedron, the tetrahedron, and the acute rhomboid. (Phil. Trans. 1813, page 51.) If other particles, having the same relative arrangement, be supposed to have the shape of oblate spheroids, the regular rhomboid will be the resulting figure; and if the spheroids be oblong instead of oblate, they will generate prisms of three or six sides. The cube also, Dr. Wollaston has shown. may be explained by the aggregation of spheroidical particles.

A method of developing the structure of crystals, by a new process, which appears greatly superior to that of mechanical division, has been described by Mr. Daniel. (Quart. Jour. i. 24.) It consists in exposing any moderately soluble salt to the slow and regulated action of a solvent. A shapeless mass of alum, for instance, weighing about 1500 grains, being immersed in 15 ounce measures of water, and set by, in a quiet place, for a period of three or four weeks, will be found to have been more dissolved toward the upper than the lower part, and to have assumed a pyramidal form. On further examination, the lower end of the mass will present the form of octahedrons and sections of octahedrons, in high relief and of various dimensions. They will be most distinct at its lower extremity, becoming less so as they ascend. This new process of dissection admits of extensive application. Borax, in the course of six weeks, exhibits eight-sided prisms with various terminations; and other salts may be made to unfold their external structure by the slow agency of water. Carbonate of lime, carbonate of strontia, and carbonate of baryta, give also distinct results, when acted upon by weak acids; and even amorphous masses of metals, which have a tendency to assume a crystalline form, such as bismuth, antimony, and nickel, when exposed to very dilute nitric acid, presented at the end of a few days distinct crystalline forms. Large crystals of sulphuret of antimony, Mr. Faraday has also found, admirably illustrate Mr. Daniel's mode of displaying crystalline texture. When such a crystal is introduced into a portion of the fused sulphuret, it begins to melt down, but not uniformly, for crystals are left more than half an inch long projecting from it. (Quart. Journ. xi. 202.) The results of these experiments, when minutely traced and investigated, afford strong confirmation to the theory, that the spheroidical is the true form of the ultimate particles of crystallized bodies.

The primitive form, and that of the integral molecule, having been experimentally determined by the dissection of a crystal, the next step is to discover the law, according to which these molecules are arranged, in order to produce, by their accumulation around the primitive figure, the great variety of secondary forms. What is most important in the discoveries of Haüy, and what constitutes, in fact, the essence of his theory, is the determination of these laws, and the precise measurement of their action. He has shown that all the parts of a secondary crystal, superadded to the primitive nucleus, consist of laminæ, which decrease gradually by the subtraction of one or more layers of integral molecules; so that theory is capable of determining the number of these ranges, and, by a necessary consequence, the exact form of the secondary crystal.

By the development of these laws of decrement, Haüy has shown how, from variations of the arrangement of the integrant molecules, a great variety of secondary figures may be produced. Their explanation, however, would involve a minuteness of detail altogether unsuitable to the purpose of this work; and I refer, therefore, for a very perspicuous statement of them, to the first and ninth volumes of the Philosophical Magazine. A popular view of the subject of crystallography may be found also in Mr. Larkin's "Introduction to Solid Geometry." London, 1820; and models of crystals, very neatly and accurately cut in wood, and either entire, or dissected so as to show their construction, may be procured from the author of that work, which will essentially facilitate the student's progress. The use of the *goniometer* is quite necessary to the accurate determination and description of the forms of crystals. When great precision is not required, and the crystal is of considerable size, the *common goniometer* will sufficiently answer the purpose; but, to obtain very correct admeasurements, the *reflective goniometer* of Dr. Wollaston is alone worthy of dependence. Both these instruments are described, and perspicuous directions given for their use, in a very useful little volume published by Mr. William Phillips, under the title of "An Elementary Introduction to the Knowledge of Mineralogy," and in the first volume of "Conversations on Mineralogy." In Mr. Brooke's "Familiar Introduction to Crystallography," also, the reader will find excellent directions for the measurement of the angles of crystals, and perspicuous rules for studying their forms; and a great portion of the first volume of Mr. Haidinger's translation of Mohs's Mineralogy is occupied in treating of the laws of crystallization, and in describing the varieties of crystallized bodies.

SECTION II.

Of Chemical Affinity, and the General Phenomena of Chemical Action.

Chemical affinity, like the cohesive attraction, is effective only at insensible distances; but it is distinguished from the latter force, in being exerted between particles or atoms of *different kinds*. The result of its action is not a mere aggregate, having the same properties as the separate parts, and differing only by its greater quantity or mass, but a new compound, in which the properties of the components have entirely or partly disappeared, and in which new qualities are also apparent. The combinations effected by chemical affinity are permanent, and are destroyed only by the interference of a more powerful force, either of the same or of a different kind.

As a general exemplification of chemical action, we may examine that which takes place between potassa and sulphuric acid. In their separate state, each of these bodies is distinguished by striking peculiarities of taste, by great causticity, and by other qualities. The alkali, on being added to blue vegetable infusions, changes their colour to green, and the acid turns them red. But if we add one substance to the other, very cautiously, and in small quantities, examining the effect of each addition, we shall at length attain a certain point, at which the liquid will possess neither acid nor alkaline qualities; it may now be safely applied to the tongue; the taste will be converted into a bitter one; and the mixture will produce no effect on blue vegetable colours. Here, then, the qualities of the constituent parts, or at least some of their most important ones, are destroyed by combination. When characteristic properties thus disappear, the bodies combined have been said to *saturate* each other; and the precise term at which this takes place has been called the *point of saturation*. It is advisable, however, to restrict this expression to weaker combinations, where there is no remarkable alteration of qualities, as in cases of solution; and to apply to the results of more energetic affinities, when attended with loss of properties, the term *neutralization*.

At the same time that the properties of bodies disappear on combination, other new qualities, both sensible and chemical, are acquired; and the affinities of the components for these substances become in some cases increased, in others diminished in energy. Sulphur, for example, is destitute of taste, smell, and action on vegetable colours; and oxygen gas is, in other respects, equally inefficient. But one of the compounds of sulphur and oxygen is intensely acid; the minutest portion instantly reddens blue vegetable infusions; and the acid is disposed to enter into energetic combination with a variety of bodies, for which its components evinced no affinity. Facts of this kind sufficiently refute the opinion of the older chemists, that the properties of compounds are *intermediate* between those of their component parts; for, in instances like the foregoing, the compound has qualities, not a vestige of which can be traced to either of its elements.

It is not, however, in all cases that the change of properties is so distinct and appreciable by the senses, as in the instances which have been just now described. In some examples of chemical union, the change is scarcely perceptible to the eye or the taste, when the chemist is nevertheless certain that combination must have taken place. This occurs chiefly in the mixture of saline solutions with each other, where a complete exchange of principles often ensues, without any evident change of properties. Examples of this kind cannot, however, be understood, till the subject of complex affinity has been first elucidated.

The existence of chemical affinity between any two bodies is inferred, therefore, from their entering into chemical combination; and that this has happened, a change of properties may be considered as a sufficient proof, even though the change may not be very obvious, and may require accurate examination to be perceived at all.

The proof, which establishes the nature of chemical compounds, is of two kinds, *synthesis* and *analysis*. Synthesis consists in effecting the chemical union of two or more bodies; and analysis in detaching them from each other, and exhibiting them in a separate state. But it is seldom that we can separate two bodies from each other without employing a third, and thus forming some fresh compound; and, when this new compound is one of known composition, the evidence of analysis is still equally complete. When we have a compound of two or more ingredients, which are themselves compounded also, the separation of the compounds from each other may be called the *proximate analysis* of the body; and the further separation of these compounds into their most simple principles, its *ultimate analysis*. Thus the proximate analysis of sulphate of potassa consists in resolving it into potassa and sulphuric acid; and its ultimate analysis is effected by decomposing the potassa into potassium and oxygen, and the sulphuric acid into oxygen and sulphur.

When the analysis of any substance has been carried as far as possible, we arrive at its most simple principles, or *elements*. By the expression *element* we are to understand, not a body that is *incapable* of further decomposition, but one which *has not yet been de-*

composed. The progress of chemical science, for several centuries past, has mainly consisted in carrying still farther the analysis of bodies, and in proving those to be compounded which had before been considered as elementary.

Beside the alteration of properties, which usually accompanies chemical action, there are certain other phenomena, which are generally observed to attend it.

1st. In almost every instance of chemical union, the *specific gravity* of the compound is greater than might have been inferred from that of its components; and this is true both of weaker and more energetic combinations. When equal weights of water and sulphuric acid are made to combine, the specific gravity of the resulting liquid is not the mean, but considerably greater than the mean. The law extends also to solids. But, though general, it is not universal; for in a very few instances, chiefly of aëriform fluids, condensation does not attend chemical union. And, in the combination of some metals with each other, even the reverse takes place; the compound being, in a few cases, specifically lighter than might have been expected, from the specific gravity of its elements, and their proportion to each other.

2dly. When bodies combine chemically, it may be received as a general fact, that their *temperature* changes. Equal weights of oil of vitriol and water, both at the temperature of 50° of Fahr. are heated, by sudden mixture, to considerably above 212°. In other examples, a contrary effect takes place, and a diminished temperature, or, in other words, a production of cold, is observed. This is all that is at present necessary to state on the subject, which will be more fully considered when we come to treat of caloric.

3dly. The *forms of bodies* are often materially changed by chemical combination. Two solids may, by their union, become fluid; or two fluids may become solid. Solids are also often changed into aëriform fluids; and, in many instances, the union of two airs, or gases, is attended with their sudden conversion into the solid state. By long exposure of fluid quicksilver to a moderate heat, we change it into a reddish scaly solid; and, by heating this solid in a retort, we obtain an aëriform fluid, or gas, in considerable quantity, and recover the quicksilver in its original form.

4thly. Change of *colour* is a frequent, but not universal, concomitant of chemical action. In some cases, brilliant colours are destroyed, as when chlorine is made to act on solution of indigo. In other instances, two substances, which are nearly colourless, form, by their union, a compound distinguished by beauty of colour, as when liquid potassa is added to very dilute syrup of violets. Certain colours appear also to belong essentially to chemical compounds, and to be characteristic of them. Thus 100 parts of quicksilver, and 4 of oxygen, invariably give a black compound; and the same quantity, with 8 parts of oxygen, afford as invariably a red compound.

SECTION III.

Of the Proportions in which Bodies combine; and of the Atomic Theory.

In the chemical combination of bodies with each other, a few leading circumstances deserve to be remarked.

1st. *Some bodies unite in all proportions;* for example, water and sulphuric acid, or water and alcohol.

2dly. *Other bodies combine in all proportions, as far as a certain point, beyond which combination no longer takes place.* Thus water will take up successive portions of common salt, until at length it becomes incapable of dissolving any more. In cases of this sort, as well as in those included under the first head, combination is weak and easily destroyed, and the qualities, which belonged to the components in their separate state, continue to be apparent in the compound.

It is necessary, however, to remark that these two deductions, though they appear to be warranted by a general survey of phenomena, are not absolutely and strictly true; for though some acids, for instance, appear to unite with water in every proportion, yet there are certain relative quantities of water and acid which form the most energetic compounds, distinguished by their permanency and by peculiar properties.

3dly. *There are many examples in which bodies unite in one proportion only;* and in all such cases the proportion of the elements of a compound must be uniform for the species. Thus hydrogen and chlorine unite in no other proportions than those constituting muriatic acid, which, by weight, are 1 of the former to 36 of the latter. Whatever of either ingredient is in excess, remains uncombined after the experiment. In cases of this sort, combination is generally energetic, and the characteristic qualities of the components are no longer observable in the compound.

4thly. *Other bodies unite in several proportions; but these proportions are definite, and, in the intermediate ones, no combination ensues.* Thus 6 parts by weight of charcoal combine with 8 of oxygen, or with 16, but with no intermediate quantity; 64 parts of copper combine with 8 of oxygen, or with 16, and with those proportions only. This law of *combination in definite proportions*, though deducible from the previous experiments of Wenzel, seems to have been first discovered and established by a series of researches undertaken with that view, by Richter of Berlin, and published between the years 1796 and 1798. The great object of that chemist was to determine the relative capacity of saturation of the acids and bases, and to represent them by a series of numbers, serving the same purpose as the Tables of Chemical Equivalents now constructed. It is unnecessary to copy the table of Richter, because the results are, for the most part, inaccurate; but, notwithstanding this, the merit of the first conception of such a table unquestionably belongs to him. Proust, afterwards, contributed to establish the law, by showing that iron and antimony do not unite with oxygen in all proportions, but only in very few determinate ones; and, in a controversy with Berthollet, which was most ably and temperately conducted on both sides, he urged convincing arguments in favour of limited combinations.

5thly. It is further remarkable, that *when one body enters into combination with another, in different proportions, the numbers indicating the greater proportions are simple multiples of that denoting the smallest proportion.* In other words, if the smallest proportion in which B combines with A be denoted by 10, A may combine with twice 10 of B, or with three times 10, and so on, but with no intermediate quantities. There cannot be more striking instances of this law than those above mentioned, of the compounds of copper and charcoal with oxygen; in which the oxygen of the last compound may, in both cases, be observed to be a multiple of that of the first by the number 2.

It is to Mr. Dalton that we are indebted for the first correct instance of such a simple multiple in the union of nitrous gas with oxygen,* and for the first distinct anticipation, founded on well-ascertained facts, of the general law of multiple combination. For, though it is due to the late Mr. Higgins, of Dublin, to state that, in an ingenious work, published in 1789, entitled *A Comparative View of the Phlogistic and Antiphlogistic Theories*, he had represented the combinations of azote with oxygen, and those of sulphur with oxygen, to form such a series, that the successive doses of oxygen are all equal multiples of the first; yet, as Dr. Wollaston has remarked, "these proportions were conceived rather than observed to occur." Little attention seems, indeed, to have been given to the subject, until the year 1808, when facts of a similar kind, but under a more tangible form, were published by Dr. Thomson and Dr. Wollaston, with regard to neutral and superacid, or subacid, salts. These facts all tended to show that the quantity of acid, combined with bases in certain super-salts, is precisely double, and in certain sub-salts precisely half, of that which is saturated by the same quantity of base in their neutral compounds.

Atomic Theory.—When the law of *definite proportions*, and that of *multiple proportions*, had been established by a sufficient number of examples, it became natural to inquire what is the reason of this uniformity, and what is the cause which renders combination in other proportions impossible. Mr. Higgins, taking for granted the correctness of the instances already quoted, had been led to conceive the theory of combination by ultimate particles, and to illustrate it by a series of diagrams, so constructed as to explain the phenomena of chemical decomposition by a comparison of the attractive forces of those particles. But, though there is much in Mr. Higgins's views that entitles him to the praise of great ingenuity, yet they are, in several respects, erroneous, and are at best to be considered as mere hints, which were not subjected, by their author, at any subsequent period, to a more copious and rigorous induction, nor indeed estimated by him, at the time; as of the importance which really belonged to them.

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* Manch. Soc. Mem. 2d Ser. vol. i. p. 250, paper read Nov. 12, 1802.

A few years afterwards, Mr. Dalton, without the slightest knowledge of the previous speculations of Mr. Higgins, formed the first distinct conception of that happy generalization, which now passes under the name of the *Atomic Theory of the Chemical Constitution of Bodies*. To this he was led by long and patient reflection on the then ascertained phenomena of chemistry. In October, 1803, he communicated to the Manchester Society an essay, containing the first general outline that was published of his speculations.* This was followed, in 1808, by a fuller, but still very concise, development of his views, in the first part of his *New System of Chemical Philosophy*. Of this theory I shall now offer such illustrations, as I trust will render it intelligible to the reader.

Though we appear, when we effect the chemical union of bodies, to operate on *masses*, yet it is consistent with the most rational view of the constitution of bodies to believe, that it is only between their *ultimate particles* that combination takes place. Of such ultimate particles, the existence, it must be confessed, cannot be demonstrated; nor can any thing more than a high degree of probability be alleged in its favour, a degree of probability, however, much outweighing any that can be produced of the infinite divisibility of matter. On this subject the immortal Newton, after reflecting on the then known chemical phenomena, has thus expressed himself (in the 31st Query, subjoined to his Treatise on Optics, 4th edition, p. 350):—"It seems to me probable that God, in the beginning, formed matter in solid, massy, hard, impenetrable, moveable particles, of such sizes and figures, and with such other properties, and in such proportions to space, as most conduced to the end for which he formed them; and that the primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard, as never to wear or break in pieces, no ordinary power being able to divide what God himself made one in the first creation," &c. To this argument, drawn from general physics, others of a similar kind have been added, by Leibnitz and Boscovich; and conclusions, of the same tendency, have, in more recent times, been deduced from astronomical observations. In an Essay on the Finite Extent of the Atmosphere, published in the Phil. Trans. for 1822, Dr. Wollaston has observed, that "since the law of definite proportions, discovered by chemists, is the same for all kinds of matter, whether solid, fluid, or elastic, if it can be ascertained that any one kind of matter consists of particles no longer divisible, we then can scarcely doubt that all other bodies are similarly constituted; and we may without hesitation conclude that those equivalent quantities, which we have learned to appreciate by proportionate numbers, do really express the relative weights of elementary atoms, the ultimate objects of chemical research." From a series of observations on the planet Jupiter, Dr. Wollaston was led to conclude, that "as this planet has not his due share of an infinitely divisible atmosphere, the universal prevalence of such a medium cannot be maintained; while, on the contrary, all the phenomena entirely accord with the supposition that the earth's atmosphere is of finite extent, limited by the weight of ultimate atoms of definite magnitude, no longer divisible by repulsion of their parts."

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* Man. Mem. 2d series, vol. i. 286. To this Essay Mr. Dalton has annexed "A Table of the Relative Weights of the Ultimate Particles of Gaseous and other Bodies."

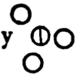
The ultimate particles, then, or atoms, of all bodies, probably consist of solid corpuscles, each of which forms a nucleus, surrounded by an atmosphere of heat. Absolute contact is not supposed ever to take place between the atoms even of inelastic bodies, since, at all temperatures to which we have access, the subtraction of heat from a body is followed, except when the body changes, or is about to change its state, by a contraction of volume. Of simple atoms, it seems most probable that the *shape* or *figure* is spherical. But, of compound atoms, consisting of a single central atom, surrounded by other atoms of a different kind, it is obvious that the figures (contemplating the solid corpuscles only) cannot be spherical; yet, if we include the atmosphere of heat, the figure of a compound atom may be spherical, or some shape approaching to a sphere.

Taking for granted that combination takes place between the atoms of bodies only, Mr. Dalton has deduced, from the *relative* weights in which bodies unite, the *relative* weights of their ultimate particles, or atoms. This is all that we are likely to determine respecting them; for it is not probable that our knowledge will ever extend beyond the *ratios* of these weights. When only one combination of any two elementary bodies exists, he assumes, unless the contrary can be proved, that its elements are united atom to atom singly. Combinations of this sort he calls *binary*. But, if several compounds can be obtained from the same elements, they combine, he supposes, in proportions expressed by some simple multiple of the number of atoms. The following table exhibits a view of some of these combinations.

1 atom of A + 1 atom of B = 1 atom of C, binary.
1 atom of A + 2 atoms of B = 1 atom of D, ternary.
2 atoms of A + 1 atom of B = 1 atom of E, ternary.
1 atom of A + 3 atoms of B = 1 atom of F, quaternary.
3 atoms of A + 1 atom of B = 1 atom of G, quaternary.

These combinations Mr. Dalton represented by characters, of which, as they have not come into general use, I shall offer only a few examples. From their figure they appear to me better adapted than symbols of any other shape, to aid our conceptions of the manner in which spherical atoms may unite. Oxygen is denoted by ○; Hydrogen by ⊙; Nitrogen by ⦶; Carbon by ●; and so of the rest.

In water we have 1 atom of oxygen united with 1 atom of hydrogen, ○⊙. The binary compound of oxygen and nitrogen may be represented by ○⦶. The ternary compound by ○⦶○.

The quaternary compound by .

As an illustration of the mode in which the relative weights of the atoms of bodies are determined, let us suppose that any two elementary substances, A and B, form a binary compound; and that they have been proved experimentally to unite in the proportion, by weight, of 5 of the former to 4 of the latter; then since, according to the hypothesis, they unite particle to particle, those numbers will express the relative weights of their atoms. But besides combining atom to atom singly, 1 atom of A may combine with 2 of B, or with 3, 4, &c. Or 1 atom of B may unite with 2 of A, or with 3, 4, &c. When such a series of compounds exists, the relative proportion of their elements ought necessarily, on analysis, to be proved to be 5 of A to 4 of B; or 5 to (4 × 2 =) 8; or 5 to (4 × 3 =) 12, &c.; or contrariwise, 4 of B to 5 of A; or 4 to (5 × 2 =) 10; or 4 to (5 × 3 =) 15. Between these there ought to be no intermediate compounds: and the existence of any such (as 5 of A to 6 of B, or 4 of B to 7½ of A) would, if clearly established, militate against the hypothesis.

To verify these numbers, it is necessary to examine the combinations of A and B with other bodies. Let us take C for example; and let us suppose that A and C form a binary compound, in which analysis discovers 5 parts of A and 3 of C. Then, if C and B are also capable of forming a binary compound, the relative proportion of its elements ought to be 4 of B to 3 of C; for these numbers denote the relative weights of their atoms. Now this is precisely the method by which Mr. Dalton deduced the relative weights of oxygen, hydrogen, and nitrogen; the two first from the known composition of water, and the two last from the proportion of the elements of ammonia. Extending the comparison to a variety of other bodies, he obtained a scale of the relative weights of their atoms; which, corrected to agree with recent experiments, is as follows:

1. In *water*, the hydrogen is to the oxygen as 1 to 8.
2. In *olefiant gas*, the hydrogen is to the carbon as 1 to 6.
3. In *carbonic oxide*, the oxygen is to the carbon as 8 to 6.

Whether, therefore, we determine the weight of the atom of carbon, from the proportion in which it combines with hydrogen, or with oxygen, we arrive at the same number, 6: an agreement which, as it occurs in various other instances, can scarcely be an accidental coincidence. In a similar manner, 8 is deducible, as representing the atom of oxygen, both from the combination of that base with hydrogen and with carbon; and 1 is inferred to be the relative weight of the atom of hydrogen from the two principal compounds into which it enters.

In selecting the body, which should be assumed as unity, Mr. Dalton has been induced to fix on hydrogen, because it is that body which unites with others in the smallest proportion by weight. Thus, in water, we have 1 of hydrogen by weight to 8 of oxygen; in olefiant gas, 1 of hydrogen to 6 of carbon; and in sulphureted hydrogen, 1 of hydrogen to 16 of sulphur. Taking for granted that all these bodies are binary compounds, we have the following scale of numbers, expressive of the relative weights of the atoms of their elements:

Hydrogen	1
Oxygen	8
Carbon	6
Sulphur	16

Drs. Wollaston and Thomson, and Professor Berzelius, on the other hand, have assumed oxygen as the decimal unit, (the first making it 10, the second 1, and the third 100,) chiefly with a view to facilitate the representation of the numerous compounds of oxygen with other bodies. This, it appears to me, is to be regretted, even though the change may be in some respects for the better, because it is extremely desirable that chemical writers should employ a standard of comparison for the weights of the atoms of bodies that may be universally and at once understood; and the hydrogen scale appears to me to deserve a preference, because the numbers composing it, so far as experiment has yet shown, are so nearly simple multiples of the weight of hydrogen taken as 1, that the deviations from strict conformity to the rule may be safely ascribed to unavoidable errors of manipulation. This will appear from consulting the Table of Berzelius, in the appendix at the end of vol. ii. of this work. But the scale, in which oxygen is taken as unity, necessarily involves the use of fractional numbers, as in the following examples:

	Oxygen, = 1.	*Oxygen*, = 10.
Hydrogen	0.125	1.25
Carbon	0.75	7.50
Nitrogen	1.75	17.5

It is true that these numbers are easily converted into each other by a simple arithmetical rule. Thus to know what number would be equivalent (oxygen being supposed 1, 10, or 100) to any known number on the hydrogen scale, say as 8 is to 1, 10, or 100, so is the known equivalent to the number sought. And, contrariwise, the equivalent in the hydrogen series to any known number on the oxygen scale is obtained by the proportion 1, 10, or 100 : 8 : : the given number : the number sought.

When any two bodies unite, so far as we know, in one proportion only, the relative weight of their atoms is in most cases determined by their combining proportion. Thus since hydrogen and chlorine unite only in the proportion by weight of 1 of the former to 36 of the latter, we consider the relative weight of the atom of hydrogen to that of the atom of chlorine to be as 1 to 36. But when one body unites, in different proportions, with another, it is necessary, in order to ascertain the weight of its atom, that we should know the smallest proportion in which the former combines with the latter. Thus, if we have a body A, 100 parts of which by weight combine with not less than 32 of oxygen, the relative weight of its atom will be to that of oxygen as 100 to 32; or, reducing these numbers to their lowest terms, as 25 to 8; and the number 25 will express the relative weight of the atom of A. But if, in the progress of science, it should be found, that 100 parts of A are capable of uniting with 16 parts of oxygen, then the relative weight of the atom of A must be doubled, for as 100 is to 16, so is 50 to 8. This example will serve to explain the changes, that have been sometimes made, in the weights of the atoms of certain bodies; changes which, it may be observed, always consist either in a multiplication, or division, of the original weight, by some simple number. It is proper, however, to state that the combining proportions are not of themselves sufficient, for reasons which will soon be assigned, to decide, in all cases, the true atomic weights of bodies.

There are (it must also be acknowledged) a few cases, in which one body combines with another in different proportions; and yet the greater proportions are not multiples of the less, by any entire number. For example, we have two oxides of iron, the first of which consists of 100 iron and about 30 oxygen; the second of 100 iron and about 45 oxygen. But the numbers 30 and 45 are to each other as 1 to 1½. It will, however, render these numbers, (1 and 1½) consistent with the law of simple multiples, if we multiply each of them by 2, which will change them to 2 and 3; and if we suppose that there is an oxide of iron (though it has not yet been obtained experimentally), consisting of 100 iron and 15 oxygen; for the multiplication of this last number by 2 and 3 will then give us the known oxides of iron.

In these cases, where we have the apparent anomaly of 1 atom of one substance, united with 1½ of another, it has been proposed, by Dr. Thomson (Ann. of Phil. v. 187), to remove the difficulty, by assuming that, in such compounds, we have 2 atoms of the one combined with 3 atoms of the other. This saves us the necessity of speaking of fractions of atoms, which, from the definition of the word *atom*, implying indivisibility, is evidently a contradiction in terms. Such combinations, it is true, are exceptions to a law deduced by Berzelius,—*that, in all inorganic compounds, one of the constituents is in the state of a single atom.* But they are in no respect inconsistent with the views of Mr. Dalton; and are, indeed, expressly admitted by him to be compatible with his hypothesis, as well as confirmed by experience. (Ann. of Phil. iii. 174.)

The investigation of the *number of atoms* in compounds is attended with considerable difficulty, and cannot always be decided by the combining proportions merely, without regard to other considerations. On this subject Mr. Dalton, in the 2d part of his New System, recently published, has made the following remarks: —"When two bodies, A and B, combine in multiple proportions; for instance, when 10 parts of A combine with 7 of B to form one compound, and with 14 to form another, we are directed by some authors to take the smallest combining proportion of one body, as representative of the elementary particle or atom of that body. Now it must be obvious to any one of common reflection, that such a rule will be more frequently wrong than right. For, by the above rule, we must consider the first of the combinations (10 A + 7 B) as containing 1 atom of B, and the second (10 A + 14 B) as containing 2 atoms of B, with 1 atom or more of A; whereas it is equally probable, by the same rule, that the compounds may be 2 atoms of A to 1 atom of B, and 1 atom of A to 1 of B respectively. For the proportions being 10 A to 7 B (or, which is the same ratio, 20 A to 14 B), and 10 A to 14 B, it is clear by the rule, that when the numbers are thus stated, we must consider the former combination as composed of 2 atoms of A, and the latter of 1 atom of A, united to 1 or more of B. Thus there would be an equal chance for right or wrong. But it is possible that 10 of A and 7 of B may correspond to 1 atom of A and 2 atoms of B; and then 10 of A and 14 of B must represent 1 atom A and 4 atoms B. Thus, it appears, the rule will be more frequently wrong than right."

A particular example may, perhaps, render the difficulty above stated more intelligible to the student. Two oxides of copper have been ascertained to exist:

1st. 8 oxygen + 64 copper = the red oxide.
2d. 16 oxygen + 64 copper = the black oxide.

Now these oxides may be variously contemplated; for we may either consider the first as the true binary compound of 1 atom of oxygen + 1 atom of metal, and the second of 2 atoms of oxygen + 1 atom of metal; or we may (with equal probability, apart from other considerations) view the second as the binary compound of 1 atom of oxygen (8) + 1 atom of copper (32), which are the same proportions as 16 to 64. The first compound will, in that case, come to be regarded as 1 atom of oxygen + 2 atoms of metal, $32 \times 2 = 64$. The latter view, in fact, is the one actually taken of these oxides by Dr. Thomson, who regards the first compound as a suboxide, and the second not, as it is generally considered, as a deutoxide, but as a protoxide. In all cases of this sort, it is necessary to examine, not only the compound of the two elementary bodies with each other, but the compounds of each with other bodies; and also to balance the probabilities derived from other considerations, such as the comparative facilities with which the respective compounds are formed or decomposed; their convertibility into each other; and the permanence or instability which belong to them.

When only one compound of any two *gaseous* elements, A and B, exists, it is most reasonable to suppose that it is composed of 1 atom of A + 1 atom of B, because an additional atom of either element (B for example) would introduce a new force, diminishing the attraction of the two elements for each other, *viz.* the mutual repulsion of the atoms of B; and this repulsion will be the greater, in proportion as we increase the number of the atoms of B. When more than one compound of two elements, A and B, exists, that which is with most difficulty decomposed is probably the binary one of atom to atom. For example, it is much more probable that water is constituted of an atom of oxygen, + an atom of hydrogen, than that the deutoxide of hydrogen should be so composed; for in the latter, one proportion of oxygen is so weakly combined as to escape merely by virtue of its own elasticity.

In every science it is necessary clearly to distinguish between what is certain, and what is merely probable. The laws of combination, in definite and multiple proportions, appear to me to belong to the former class; but the generalization, which explains those truths by speculations respecting atoms, must be acknowledged, in its present state, to be entirely theoretical. The probabilities, however, in favour of this theory, increase with the progress of science. That bodies consist of ultimate indivisible atoms;—that these ultimate atoms have in different bodies different weights;—that it is only between these atoms that chemical combination takes place;—and then either between single atoms, or by simple multiples of atoms,—are propositions which may be considered as safe ground for our future reasonings. But the details of the theory, it must be acknowledged, are still open to further investigation, and no one is more aware than the illustrious author of it himself, that we still want data sufficiently exact for determining the relative weights of the atoms of many bodies, especially of those which are known to us only in a gaseous state. (See his New System, vol. ii. p. 351.) No better service could be rendered to chemical science than the accurate determination of these most important data, which ought not to rest on the testimony of any one individual, however great his reputation or his skill, but to be decided by the concurring testimony of witnesses, competent to the task and uninfluenced by theoretical predilections.

Before dismissing the consideration of the proportions in which bodies combine, it will be proper to notice a few general principles, which, though they are connected with the atomic theory, have been derived from experience.

1. When we have ascertained the proportion in which any two or more bodies, A B C, &c. of one class neutralize another body X of a different class, it will be found that the same relative proportions of A B C, &c. will be required to neutralize any other body of the same class as X. Thus, since 40 parts of real sulphuric acid, and 54 of real nitric acid, neutralize 48 of potassa, and since 40 of sulphuric acid neutralize 28 of lime, we may infer that 54 of nitric acid will neutralize the same quantity (28) of lime. The great importance of this law will readily be perceived, not only as it enables us to anticipate, but also to correct, the results of analysis.

2dly. If the quantities of two bodies, A and B, that are necessary to saturate a given weight of a third body, X, be represented by q and r, these quantities may be called *equivalents*, and may be expressed by a series of numbers. In the example above cited, 40 parts of sulphuric acid and 54 of nitric acid, are equivalents of each other, and also of 48 potassa. By some writers, *proportion* and *proportional* are used as terms synonymous to equivalent: and, as the relative weights of the ultimate particles of bodies are deduced from the proportions in which they combine, it is evident that the same series of numbers will express also the *atomic weights* of bodies. In the Appendix will be found an extensive *Table of Equivalent or Atomic Weights*, the foundation of which was sagaciously laid by Dr. Wollaston, in 1814, on the best analyses then known; and it has been since enlarged and corrected by the labours of subsequent chemists. By adapting a table of this sort to a moveable scale, on the principle of Gunter's sliding rule, Dr. Wollaston constructed an instrument, called the *Logometric Scale of Chemical Equivalents*, which is capable of solving, with great facility, a number of problems, interesting both to the scientific and practical chemist.* (Phil. Trans. 1814.) Some applications of this instrument, to researches into the constitution of organic bodies, have been pointed out by Dr. Prout. (Ann. of Phil. vi. 270.)

Law of Volumes.

An extension of the law of definite proportions, so far as respects aëriform bodies, has been proposed by Gay Lussac, namely, that they combine in proportions determinable by *volume*, the ratios being 1 *volume* of A to 1 of B, or 1 to 2, or 1 to 3, &c. Water, for example, results from the union of 2 volumes of hydrogen gas with 1 volume of oxygen gas; muriate of ammonia from one volume of muriatic acid gas + 1 of ammonia; nitrous gas from 1 measure of oxygen + 1 of nitrogen; nitrous oxide from 1 oxygen + 2 nitrogen; nitrous acid from 2 oxygen + 1 nitrogen.

When the product remains gaseous, there is either no condensation of elements, or, if there be a condensation, it bears some simple and uniform relation to the volumes of the gases which have combined: Thus,

vol.		*vol.*		*vol.*
1 of chlorine	+	1 hydrog.	=	2 muriatic acid gas.
2 of hydrog.	+	1 oxyg.	=	2 aqueous vapour.
1 of nitrog.	+	½ oxyg.	=	1 nitrous oxide.
1 of nitrog.	+	1 oxyg.	=	2 nitrous gas.

Having established the law of definite and multiple volumes, in a variety of cases admitting of the actual measurement of the volumes before and after combination, Gay Lussac extended it to other cases of chemical union, where one of the bodies is not known to us as a gas in its separate form. For example, we have never yet seen gaseous carbon, but we conclude from analogy that, at a sufficiently high temperature, it would be capable of being volatilized. We know, also, that by combination with oxygen and with hydrogen, carbon furnishes gaseous compounds, and that oxygen gas, by having charcoal burned in it, has its specific gravity increased from 1.1111 to 1.5277, its volume remaining the same. The difference between these two numbers will, therefore, denote the weight of carbon, which a volume of oxygen has absorbed; viz. 1.5277—1.1111 = 0.4166. From analogy, Gay Lussac concludes, that 1 volume of gaseous carbon unites with 1 volume of oxygen gas to form carbonic acid, and that 0.4166 represents the weight of the former. But it is evident that the facts are equally well explained, if we suppose a greater or less volume of gaseous carbon to be so combined, provided its weight be proportional; for example, 2 volumes of carbon weighing half the above number, or 0.2083 × 2, may unite with 1 volume of oxygen to form carbonic acid. In all such instances, then, it is matter of theory that bodies, not known to us as gases, unite in volumes which are equal, or multiples, or sub-multiples, of those of known gases; nor can we be certain, admitting the probability of such combinations, that the volumes assigned are actually the true ones.

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* This instrument (or similar ones, accommodated to the present state of chemical science, and in which hydrogen is made unity) may be had, with printed instructions, of the makers of philosophical apparatus, and at so trifling a cost, that I consider a plate of it to be quite unnecessary. A common sliding rule will be found a most useful accompaniment to it. This also, with a book of instructions for its use, by Mr. Bevan, may be had of Mr. Carey, London. Facility in the use of the common sliding rule will be found extremely useful to the chemist, especially in all operations of arithmetic, in which proportion is concerned.

No good reason could have been given *à priori*, why gaseous bodies should unite in these simple proportions as to volume; but the principle being established, it is evident that the law of volumes, and that of determinable weights, equally confirm the general principles of the atomic theory. The first indeed expresses nothing more than the laws of definite and multiple proportions under another form, proportional *volumes* being contemplated instead of proportional *weights*. But if we admit the law, as thus modified, the question still recurs, why does combination take place among gases in definite and in multiple volumes? To this question, the atomic theory furnishes the only answer, *viz*. that in a definite volume of every gas, the pressure and temperature being supposed the same, we have a definite number of ultimate particles or atoms, which is always the same for each gas so circumstanced. But it may still be doubted, whether equal volumes of different gases contain equal or unequal numbers of atoms. According to Mr. Dalton's view, 1 volume of oxygen gas contains as many ultimate atoms as 2 volumes of hydrogen. Berzelius, on the contrary, supposes that in equal volumes of oxygen, hydrogen, and some other gases, we have equal numbers of atoms. If the latter opinion were true, the relative weights of the atoms of such gases would be correctly expressed by their specific gravities. Hydrogen, for instance, being 16 times lighter than oxygen, if we take 1 for the atomic weight of hydrogen, 16 must be taken for that of oxygen, and we must double the atomic weight of every substance which has been deduced from the combination of that substance with oxygen. Carbon, for instance, must be represented by 12, sulphur by 32, and so of the rest. This has actually been done by Berzelius, and it is necessary that in referring to his table of atomic weights, given in the Appendix, the reader should be aware that they are, for the most part, even when corrected by the rule given, p. 54, nearly double of those received in this country. That they are not so exactly, is owing to his having derived them in many cases from experimental data of his own, or of other continental chemists.

On the law of volumes, as first generalized by M. Gay Lussac, were founded some interesting speculations, published anonymously in Dr. Thomson's Annals of Philosophy, for Nov. 1815, but since acknowledged by Dr. Prout, *On the Relation between the Spe-*

cific Gravities of Bodies in their Gaseous State, and the Weight of their Atoms. Assuming atmospheric air to be constituted of four volumes of azote, and one volume of oxygen, and considering the weight of the atom of oxygen as 10, and that of the atom of azote as 17.5, he finds the specific gravities to be

Of oxygen gas - - - - - - -	1.1111
Of azote - - - - - - - - -	.972

From the specific gravity and composition of ammonia he deduces the specific gravity of hydrogen gas to be 0.0694. The specific gravity of oxygen thus obtained is, therefore, exactly 16 times that of hydrogen, and the specific gravity of azote just 14 times. By a similar method, he inferred the specific gravity of other gases, and also of some elementary substances in a gaseous state, that do not at ordinary temperatures exist in that state; and he embodied the results in the form of tables, from which he drew the then remarkable conclusion, that *all the elementary numbers, hydrogen being considered as* 1, *are multiples of the atomic weight of hydrogen by a whole number.* Dr. Prout also first pointed out that to find the specific gravity of any substance in the state of gas, we have only to multiply half the specific gravity of oxygen gas by the atomic weight of the substance, with respect to oxygen. For instance, the combining ratio in volume between oxygen and iodine is as $\frac{1}{2}$ to 1, and the combining ratio in weight as 1 to 15.5. Now .5555, the density of half a volume of oxygen, multiplied by 15.5, gives 8.61111, for the specific gravity of vaporous iodine. In several instances, the numbers thus deduced have been confirmed by a valuable series of experiments, undertaken by Dumas, with the view of determining the atomic weights of bodies by the density of their vapours. (Ann. de Chim. et de Phys. Dec. 1826.) The specific gravity of gaseous iodine, for example, Dumas finds by experiment to be 8.716, a deviation from the theoretical number (8.6111) of too small amount to impeach the accuracy of the method of reasoning, from which the latter number had been derived.

Laws of Professor Berzelius.

It may perhaps be expected that in this chapter I should take some notice of the contributions of Professor Berzelius, of Stockholm, to the Atomic Theory, and of his peculiar views, as stated in an 8vo. volume entitled *Essai sur la Théorie des Proportions Chimiques, Paris,* 1819; and, also, in the article *Proportions Determinate* of Dr. Brewster's Edinburgh Encyclopædia. The facts contributed by that able and zealous chemist, in proof of the laws of definite and multiple proportions, can scarcely be too highly valued. For many years, he has been employed in conducting analyses with consummate skill and unwearied industry. But in deducing general laws, he does not seem to have been equally fortunate; for all those which are correct are obvious corollaries from the atomic doctrines of Mr. Dalton, and those which do not flow from that doctrine are generally erroneous. This I shall have occasion to show hereafter, especially in connexion with the general observations prefixed to the chapter on Metals. With the nomenclature of Berzelius, and his method of notation, it is, however, quite essential that the student should obtain an acquaintance, in order to avail himself of the vast fund of valuable information which that philosopher, and others of his school, have shrouded (unfortunately for science) in language and symbols calculated to perplex the reader. To avoid, however, any interruption to the subject in this place, I shall prefix the necessary information to his table of atomic weights. (See the Appendix, vol. ii.)

SECTION IV.

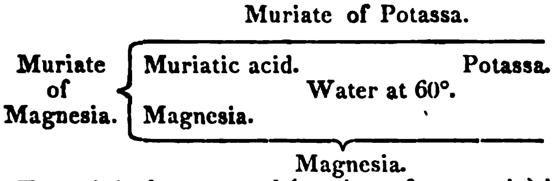
Of Elective Affinity.

An important law of affinity, deduced chiefly from the phenomena of chemical decomposition, is, that one body has not the same force of affinity towards a number of others, but attracts them unequally. Thus A will combine with B in preference to C, even when these two bodies are presented to it under equally favourable circumstances. Or when A is united with C, the application of B will detach A from C, and we shall have a new compound, consisting of A and B, C being set at liberty. Such cases are examples of what is termed in chemistry *simple decomposition*, by which it is to be understood that a body acts upon a compound of two ingredients, and unites with one of its constituents, leaving the other at liberty. And as the forces of affinity of one body to a number of others vary, this body has been metaphorically represented as making an election; and the affinity has been called *single elective affinity*. Thus, if to liquid muriate of lime, consisting of lime and muriatic acid, we add potassa, the muriatic acid exerts a stronger elective affinity for the potassa than for the lime; and the lime falls down in the state of a powder, or is *precipitated*. Of facts of this kind a great variety have been comprehended in the form of tables, the first idea of which occurred nearly a century ago to Geoffroy, a French chemist. The substance, whose affinities are to be expressed, is placed at the head of a column, and is separated from the rest by a horizontal line. Beneath this line are arranged the bodies with which it is capable of combining, in the order of their respective forces of affinity; the substance, which it attracts most strongly, being placed nearest to it, and that for which it has the least affinity at the bottom of the column. The affinities of muriatic acid, for example, are exhibited by the following series :—

MURIATIC ACID.

Baryta,
Potassa,
Soda,
Lime,
Ammonia,
Magnesia, &c. &c.

Simple decompositions may be expressed also by another form, contrived by Bergman. Thus the following scheme illustrates the decomposition of muriate of magnesia by potassa:—



The original compound (muriate of magnesia) is placed on the outside and to the left of the vertical bracket. The included space contains the original principles of the compound, and also the body which is added to produce decomposition. Above and below the horizontal lines are placed the new results of their action. The point of the lower horizontal line being turned downwards, denotes that the magnesia falls down or is precipitated; and the upper line, being perfectly straight, shows that the muriate of potassa remains in solution. If both the bodies had remained in solution, they would both have been placed above the upper line; or, if both had been precipitated, beneath the lower one. If either one or both had escaped in a volatile form, this would have been expressed by placing the volatilized substance above the diagram, and turning upwards the middle of the upper horizontal line. And since decompositions vary under different circumstances, it is necessary to denote, by the proper addition to the scheme, that the bodies are dissolved in water of the temperature of 60°.

No chemical facts can appear, on first view, more simple or intelligible than those which are explained by the operation of single elective affinity. It will be found, however, on a more minute examination, that this force, abstractedly considered, is only one of several causes which are concerned in chemical decompositions, and that its action is modified, and sometimes even subverted, by counteracting forces.

SECTION V.

Of the Causes which modify the Action of Chemical Affinity.

The order of decomposition is not, as might be inferred from the law of elective affinity, invariable; but, in certain cases, may even be reversed. Thus, though A may attract B more strongly than either A or B is attracted by C, yet, under some circumstances, C may be employed to decompose partially the compound A B. Again, if we mix together A, B, and C, using the two first in the proportions required to neutralize each other, it will be found in some cases that A and B have not combined to the exclusion of C, but that we have a compound of B with A, and another of B with C, in proportions regulated by the quantities of A and C which have been employed. Facts of this kind have been long known to chemists. It had been ascertained, for example, before the time of Bergman, that sulphate of potassa, a salt composed of sulphuric acid and potassa, is partly decomposed by nitric acid, although the nitric has a weaker affinity than the sulphuric acid for that alkali. Examples of the same kind have since been multiplied by Berthollet, who has asserted that in the following, as well as in other cases, the body first mentioned, in each line, decomposes a compound of the second and third, although its attraction for the second is inferior to that of the third for the second.

1. Potassa separates sulphuric acid from baryta.
2. Lime separates sulphuric acid from potassa.
3. Potassa separates oxalic acid from lime.
4. Nitric acid separates lime from oxalic acid.
5. Potassa separates phosphoric acid from lime.
6. Potassa separates carbonic acid from lime.
7. Soda separates sulphuric acid from potassa.

These instances of *reciprocal decomposition*, and a variety of similar ones, are explained, according to the views of Berthollet, on the following principles:

1. When two substances are opposed to each other with respect to a third, as in the foregoing examples, they may be considered as antagonist forces; and they share the third body between them in proportion to the intensity of their action. But this intensity, according to Berthollet, depends not only on the *energy of the affinities*, but on the *quantities* of the two bodies opposed to each other. Hence a larger quantity of one of the substances may compensate a weaker affinity, and the reverse. To the absolute weight of a body, multiplied by the degree of its affinity, he has given the name of *mass*, a term in some degree objectionable from the different meaning which is affixed to it in mechanical philosophy. As an illustration, let us suppose (what is not accurate in point of fact,) that the affinity of baryta for muriatic acid is twice as strong as that of potassa, or that these affinities are respectively denoted by the numbers 4 and 2. In this case the same *mass* will result from 4 parts of baryta as from 8 of potassa; because the same product (16) is obtained in each instance, by multiplying the number indicating the affinity into that denoting the quantity; for 4 (the affinity of baryta) multiplied by 4 (the quantity assumed in this example, is equal to 16; and 2 (the affinity of potassa) multiplied by 8 (its quantity) is also equal to 16. In this case, therefore, to divide equally a portion of muriatic acid between baryta and potassa, these bodies should be employed in the proportion of 2 of the former to 4 of the latter.

The influence of quantity explains also the difficulty which, in many instances, is observed in effecting the total decomposition of a compound of two principles by means of a third. The immediate effect of a third body C, when added to a compound A B, is to abstract from B a portion of the substance A; and consequently a portion of B is set at liberty, the attraction of which for A is opposed to that of the uncombined part of C. The farther this decomposition is carried, the greater will be the proportion of B, which is brought into an uncombined state; and the more powerfully will B oppose any farther tendency of C to detach the substance A. At a certain point, the affinities of B and C for A will be exactly balanced, and the decomposition will proceed no farther. In several cases, it is acknowledged by Berthollet, a third body separates the whole of one of the principles of a compound; but this he supposes to happen in consequence of the agency of other extraneous forces, the nature of which remains to be pointed out.

2dly. *Cohesion* is a force, the influence of which over the chemical union of bodies, has already been explained in a former section; and other illustrations of its interference will be given, when we consider the subject of the limitations to chemical combination.

3dly. *Insolubility* is another force, which essentially modifies the exertion of affinity. It is to be considered, indeed, merely as the result of cohesion, with respect to the liquid in which the effect takes place.

When a soluble substance and an insoluble one are presented, at the same time, to a third, for which they have nearly an equal affinity, the soluble body is brought into the sphere of action with great advantages over its antagonist. Its cohesion at the outset is but little, and by solution is reduced almost to nothing; while that of the insoluble body remains undiminished. The whole of the soluble substance also exerts its affinity at once; while a part only of the insoluble one can oppose its force. Hence the soluble substance may prevail, and may attach to itself the greatest proportion of the third body, even though it has a weaker affinity than the insoluble one to the subject of combination.

Insolubility, however, under certain circumstances, is a force which turns the balance in favour of the affinity of one body when opposed to the affinity of another. For example, if to the soluble compound, sulphate of soda, we add baryta, the new compound, sulphate of baryta, is precipitated the instant it is formed; and, being removed from the sphere of action, the soda can exert no effect upon it by its greater quantity or mass. For the same reason, when soda is added to sulphate of baryta, the sulphate is protected from decomposition both by its insolubility and by its cohesion.

These facts convinced Berthollet that the order of precipitation, which was formerly assumed as the basis of tables of elective affinity, can no longer be considered as an accurate measure of that force; and that the body, which is precipitated, may, in some cases, be superior in affinity to the one which has caused precipitation. In these cases, a trifling superiority in affinity may be more than counterbalanced by the cohesive force, which causes insolubility.

4thly. *Great specific gravity* is a force which must concur with insolubility or cohesion in originally impeding combination; and, when chemical union has taken place, it must come in aid of affi nity, by removing the new compound from the sphere of action. It is scarcely necessary to enlarge on the operation of a force, the nature of which must be so obvious.

5thly. *Elasticity.* Cohesion, it has already been stated, may prove an impediment to combination; and, on the other hand, it is possible that the particles of bodies may be separated so widely, as to be removed out of the sphere of their mutual attraction. Such appears to be the fact with regard to a class of bodies called airs or gases. The bases of several of these have powerful attractions for the bases of others, and for various liquids, and yet they do not combine on simple admixture, but strong mechanical pressure brings their particles sufficiently near to be within the influence of their mutual attraction, and combination then ensues.

Again, if two bodies, one of which has an elastic and the other a liquid form, be presented at the same time to a solid, for which they have both an affinity, the solid will unite with the liquid in preference to the gas. Or, if we add to the compound of an elastic substance with an inelastic one, a third body also inelastic, the two which are inelastic combine, to the exclusion of the elastic body. For example, if to the compound of potassa and carbonic acid we add sulphuric acid, the latter acid, acting both by its affinity and its quantity, disengages a portion of carbonic acid. This, by its elasticity, is removed from the sphere of action, and presents no obstacle to the farther operation of the sulphuric acid. Hence elastic bodies act only by their affinity; whereas liquids act both by their affinity and quantity conjoined. And though the affinity of the liquid, abstractedly considered, may be inferior to the affinity of the elastic body, yet, aided by quantity, it prevails. In the above instances, the whole of the elastic acid may be expelled by the fixed acid; whereas, as it has already been observed, decomposition is frequently incomplete, if the substance which is liberated remain within the sphere of action.

6thly. *Efflorescence* is a circumstance which occasionally influences the exertion of affinity; but this is only of very rare occurrence. The simplest example of it is that of lime, and muriate of soda. When a paste composed of these two substances, with a great excess of lime, is exposed, in a moist state, to the air, the lime, acting by its quantity, disengages soda from the common salt, which appears in a dry form, on the outer surface of the paste, united with carbonic acid absorbed from the atmosphere. In this case the soda, which is separated, being removed from contiguity with the interior part of the mass, presents no obstacle to the farther action of the lime, and the decomposition is carried farther than it would have been, had no such removal happened.

7thly. The influence of *temperature* over chemical affinity is extremely extensive and important; but, at present, a very general statement only of its effects is required. In some cases an increased temperature acts in promoting, and at others in impeding, chemical combination; and it materially affects also the order of decompositions.

An increased temperature promotes chemical union by diminishing or overcoming cohesion. Thus metals unite by fusion, and several salts are more soluble in hot than in cold water. Whenever heat is an obstacle to combination, it produces its effect by increasing elasticity. Hence water absorbs a less proportion of ammonia at a high than at a low temperature. A reduction of the temperature of elastic bodies, by lessening their elasticity, facilitates their union with other substances. In certain cases, an increased temperature has the effect both of diminishing cohesion and increasing elasticity. When sulphur is exposed to oxygen gas, no combination ensues until the sulphur is heated; and, though the elasticity of the gas is thus increased, yet the diminution of cohesion of the solid is more than proportionate, and chemical union ensues between the two bodies.

8thly. The *electrical state* of bodies has a most important influence over the chemical union. This, however, is a subject which will be treated at length in a subsequent chapter on *Electro-chemistry*.

9thly. *Mechanical pressure* is another force which has considerable influence over chemical affinity. With respect to solid bodies, its agency is not frequent; but we have unequivocal examples of its operation in cases where detonation is produced by concussion. The effects of pressure are chiefly manifested in producing the combination of aëriform bodies either with solids, with liquids, or with each other; and, in preserving combinations, which have been already formed, under circumstances tending to disunite them. Chalk, for example, is a compound of lime and carbonic acid; and these bodies, by the simple application of an intense heat, are separable from each other; but, under strong pressure, a heat may be applied sufficient to melt the chalk, without expelling the carbonic acid. It is this principle (the influence of pressure in opposing chemical decomposition) that is the foundation of Dr. Hutton's ingenious Theory of the Earth.

Such are the most important circumstances that modify the exertion of chemical affinity. Of their influence, sufficient illustrations have been given to prove, that in every case of combination and decomposition, we are not to consider the force of affinity abstractedly, but are to take into account the agency of other powers, as cohesion, quantity, insolubility, elasticity, efflorescence, and temperature. But we cannot concede to Berthollet, that these accessary forces are, of themselves, sufficient to explain all the phenomena to which he has applied them; for no one can doubt that chemical decompositions and combinations are, in a great majority of cases, produced independently of those accessary forces, and are due to the different degrees of affinity inherent in the heterogeneous particles of bodies. Still less can the extension of the principles of Berthollet be admitted, to account for the uniformity of proportions in which bodies combine; for, besides that the cause assigned is inadequate to the effect, we find in the atomic theory the only satisfactory explanation of the union of bodies in definite and in multiple proportions. That the theory of Berthollet is of much more limited application than he supposed, will appear also from the following considerations.

1st. It has been shown by Professor Pfaff, of Kiell, (77 Ann. de Chim. p. 259,) that, in various cases, where two acids are brought into contact with one base, the base unites with one acid, to the complete exclusion of the other. When, for example, to a given weight of lime, quantities of sulphuric and tartaric acids are put, either of which would exactly neutralize the lime, the sulphuric acid unites with the lime, to the entire exclusion of the tartaric. Similar evidence of a superior affinity of the sulphuric acid, over that of the oxalic, is obtained by placing those acids in contact with as much oxide of lead as would exactly saturate either of them. Now, in these instances, and in a multiplicity of others of the same kind, we cannot explain the effect by the extraneous force of cohesion, which, judging from the degree of insolubility, is greater in the original than in the new compound, and can therefore have had no share in the production of the latter.

2dly. Some of the cases, which have been before quoted from Berthollet, to show the reciprocal displacement of two bodies by each other from a third, are most probably examples, not of *single* elective affinity, in which three bodies only are concerned; but of *complex* affinity, in which the attractions of four bodies are brought into action. In the first case, for example, there is reason to believe that sulphuric acid is displaced from baryta, not by pure potassa, but by potassa which has absorbed carbonic acid from the atmosphere.

3dly. In other cases, the consideration of the affinities of two bodies, A and B, for a third, C, is complicated with this circumstance, that the neutral compound of A and B has an affinity for a farther proportion of one of its ingredients. If, then, C be brought into contact with the compound A B, we may have, acting at the same moment, the affinity of C for A, which partly decomposes the compound A B; and the affinity of the undecomposed part of A B for an additional portion of B. For instance, when nitric acid acts on sulphate of potassa, some nitrate of potassa is formed; and the sulphuric acid, which is set at liberty, uniting with the undecomposed sulphate of potassa, composes a new salt, consisting of sulphate of potassa with an additional proportion of sulphuric acid.

4thly. It is a strong objection to the theory of Berthollet that, in some cases, decompositions happen, which, according to his views, ought not to take place; and that, in others, decompositions do not ensue, which the theory would have led us to have anticipated.

5thly. The theory is objectionable, inasmuch as, in several instances, forces are supposed to operate, before the bodies exist to which those forces are attributed. It is inconceivable, for instance, that the cohesion, or insolubility, of sulphate of baryta, can have any share in producing the decomposition of sulphate of potassa by that earth; for the insolubility of sulphate of baryta can have no agency till that compound is formed, which is the very effect to be explained.

Notwithstanding these objections to the theory of Berthollet, when carried so far as has been done by its author, in the explanation of chemical phenomena, it must still be admitted that the extraneous forces, pointed out by that acute philosopher, have some influence in modifying the effects of chemical affinity. But these forces are entitled only to be considered as secondary causes, and not as determining combinations or decompositions, nor as regulating the proportions in which bodies unite, independently of the superior force of chemical affinity.

SECTION VI.

Of the Estimation of the Forces of Affinity.

The affinities of one body for a number of others are not all of the same degree of force. This is all that the present state of our knowledge authorizes us to affirm; for we are ignorant *how much* the affinity of one body for another is superior to that of a third. The determination of the precise forces of affinity would be an important step in chemical philosophy: for its phenomena might then be reduced to calculation; and we should be enabled to anticipate the results of experiment. That the force of chemical affinity must be prodigiously great, is evident from its effect in preserving the combination of water with some bodies (the alkalies for instance) when exposed to a violent heat, notwithstanding its great expansive force, and though water is not essential to the constitution of those bodies.

The observed order of decomposition, it has already been stated, does not enable us to assign the order of the forces of affinity; because, in many decompositions, extraneous forces are concerned. Other methods of determining the problem have therefore been attempted.

When the surface of one body is brought into contact with another surface of the same kind, as when the smooth surfaces of a divided leaden bullet are pressed together, they adhere by the force of cohesion, their particles being all of *the same kind.* But when the surfaces of different bodies are thus brought into apparent contact, it seemed to Guyton reasonable to suppose that their adhesion arises from chemical affinity, because their particles are of *different kinds.* He proposed, therefore, the comparative force, with which different surfaces adhere, as a measure of chemical affinity. His experiments were made on plates of different metals, of precisely the same size and form, suspended by their centres from the arm of a sensible balance. The lower surfaces of these plates were successively brought into contact with mercury, which was changed for each experiment, and the weight was observed, which it was necessary to add to the opposite scale, in order to detach the several metals. Those which required the largest weight were inferred to have the greatest affinity; and it is remarkable, that the order of affinities, as determined in this way, correspond with the affinities as ascertained by other methods. The following were the results:

Gold adhered to mercury with a force of -	446 grains.
Silver, - - - - - - - - -	429
Tin, - - - - - - - - -	418
Lead, - - - - - - - - -	397
Bismuth, - - - - - - - -	372
Zinc, - - - - - - - - -	204
Copper, - - - - - - - - -	142
Antimony, - - - - - - - -	126
Iron, - - - - - - - - -	115
Cobalt, - - - - - - - -	8

This method, it must be obvious, is of too limited application to be of much utility; for few bodies have the mechanical conditions, which enable us to subject them to such a test. How, for example, could the affinities of acids for alkalies be examined on this principle? It may be doubted, also, whether, in the cases to which it may be applied, it does not measure facility of combination, rather than the actual strength of affinity.

To determine accurately the relative forces of affinity which a body (A) of one class exerts towards a number of others (X, Y, Z) of a different class, and to express them by numbers, Mr. Kirwan proposed the quantities of the latter which are required to produce neutralization. With this view, he made numerous experiments; but as their results have been shown to be inaccurate, I shall employ, in explaining the principle of his method, the more correct numbers, which have been since ascertained by other chemists.

40 Parts of SULPHURIC ACID require for Neutralization		48 Parts of POTASSA require	
78 parts	of baryta.	54	of nitric acid.
52	of strontia.	44	of carbonic acid.
48	of potassa.	40	of sulphuric acid.
32	of soda.	37	of muriatic acid.
28	of lime.		
20	of magnesia.		
17	of ammonia.		

In judging of the affinities *of the same acid for different bases*, Mr. Kirwan assumed that they are represented by the numbers indicating the quantities of each base required for neutralization. Thus, because 40 parts of sulphuric acid neutralize 78 of baryta, and 48 of potassa, he concluded the affinity of the former to that of the latter to be in the proportion of 78 to 48. So far the inference corresponds with the order of decomposition; baryta, for example, takes sulphuric acid from potassa. But even in this case, we are not entitled to conclude that these numbers express accurately the relative affinities of different bases for the same acid. And if we apply the rule to the numbers in the second column, we shall find it to fail entirely; for both nitric and carbonic acids are separated from potassa by sulphuric acid, although the capacity of saturation in the latter is expressed by the lowest number. Mr. Kirwan was, therefore, driven to the necessity of establishing a precisely opposite rule in determining the affinities of different acids for the same base, and of assuming that they are *inversely* proportionate to the quantities of the saturating acid. Thus the affinity of nitric acid for potassa would be represented by 40, and that of sulphuric acid by 54. This, however, involves a contradiction; since it is implied that in one set of cases a greater quantity of the saturating principle indicates a stronger affinity, and that in the other a less quantity implies a stronger affinity.

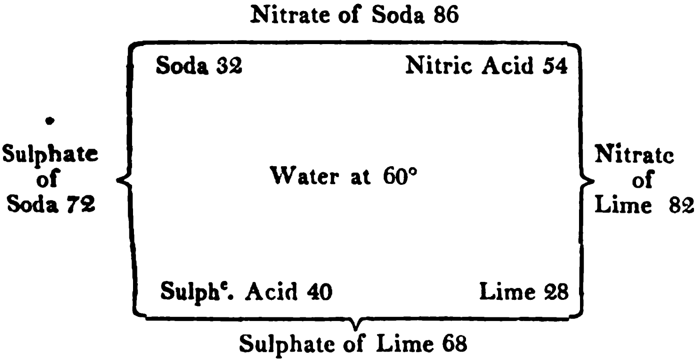
Since neutralization is an effect of chemical affinity, which must in all cases bear a proportion to its cause, it was argued by Berthollet, that the substance which, in the *smallest quantity*, neutralizes another, is the one possessing the strongest affinity. Thus because 17 parts of ammonia go as far in neutralizing a given weight of any acid, as 78 of baryta, he concluded that the relative affinities of ammonia and baryta for acids are inversely as those numbers. That ammonia is expelled from all acids by baryta, he explains by the action of an extraneous force (elasticity) which exists in ammonia, and turns the balance in favour of the fixed bases. But this explanation is liable to an obvious objection; for, as the elasticity of ammonia is suppressed by combination with sulphuric acid, what (it may be asked) but a stronger affinity for that acid, existing in all the substances standing above ammonia in the Table, can determine the first commencement of decomposition.

It is sufficient to have given this brief view of the methods employed to express numerically the forces of affinities, to show that the problem has not yet been solved;—that they cannot be appreciated by the adhesion of surfaces;—and that they are not denoted by those equivalent numbers, or atomic weights, that have been deduced from the proportions in which bodies combine.

SECTION VII.

Of Complex Affinity.

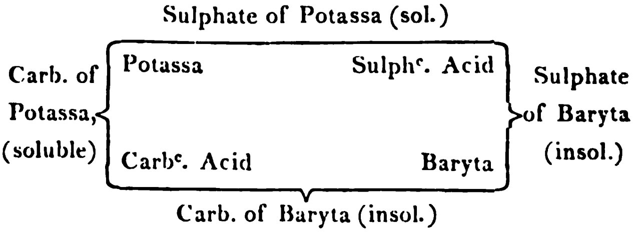
Under the more general name of *complex affinity*, Berthollet includes all those cases of decomposition which have hitherto been considered as produced by the action of four affinities, commonly denominated *double elective affinity*. It frequently happens that the compound of two bodies cannot be destroyed either by a third or a fourth separately applied; but if the third and fourth be combined, and placed in contact with the former compound, a decomposition or exchange of principles will ensue. Thus when lime water is added to a solution of the sulphate of soda, no decomposition happens, because the sulphuric acid attracts soda more strongly than it attracts lime. If nitric acid be applied to the same compound, its principles remain undisturbed, because the sulphuric acid attracts soda more strongly than the nitric. But if the lime and nitric acid, previously combined, be mixed with the sulphate of soda, a double decomposition is effected. The lime, quitting the nitric acid, unites with the sulphuric; and the soda, being separated from the sulphuric acid, combines with the nitric. These decompositions are rendered more intelligible by the following diagram, contrived by Bergman, the form of which may be readily modified, so as to adapt it to more complicated cases.



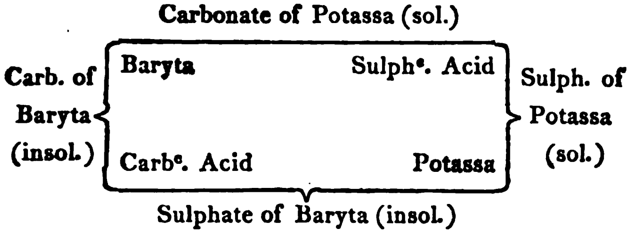
On the outside of the vertical brackets are placed the original compounds; and above and below the diagram, the new compounds. The upper line, being straight, indicates that the nitrate of soda remains in solution; and the middle of the lower line, being directed downwards, that the sulphate of lime is precipitated. The figures, which form part of the diagram, are the equivalent numbers of the original and newly-formed compounds, as well as of their proximate elements. Thus, by mingling 72 parts of sulphate of soda, consisting of 32 soda and 40 sulphuric acid, with 82 of nitrate of lime, = 54 nitric acid and 28 lime, the products are 68 of sulphate of lime (28 base + 40 acid), and 86 nitrate of soda (32 base + 54 acid). When the original compounds are, as in this instance, perfectly neutral, the new products will be found equally so. This general fact, first noticed by Wenzel, is a consequence of the law of combination in definite proportions; for, under all circumstances, equivalent quantities of acids and bases, whether directly united or mutually transferred, as in the above instance, must exactly neutralize each other.

To the affinities tending to produce decomposition, Mr. Kirwan gave the name of *divellent affinities*, and to those preserving the original compounds, that of *quiescent* affinities. These he attempted to express by numbers, so chosen as to enable him to anticipate the results of experiment. It is sufficient to observe, that, for reasons which I have already stated, this attempt entirely failed. We may still, however, retain the expressions *divellent* and *quiescent*, as a convenient mode of speaking of a certain class of chemical decompositions. Over these phenomena, the extraneous causes, pointed out by Berthollet, appear also to have considerable influence. That of *quantity* is shown by the fact, that if two salts be mixed together in certain proportions, decomposition will ensue, but not if mixed in other proportions. Thus from the mingled solutions of two parts of muriate of lime and one of nitrate of potassa, we obtain muriate of potassa; but not from equal weights of the two salts. Insolubility, or precipitation, has also a considerable influence on the result. When this occurs, the influence of quantity is destroyed, as in the case of sulphate of potassa and muriate of baryta. Elasticity, and an increased temperature (which operates by increasing elasticity), and the reverse of this, or a greatly *diminished* temperature, have also a powerful influence in promoting the action of complex affinities. Thus of four principles, two of which are volatile and two fixed, the two which are volatile will be most disposed to unite together at a high temperature, even though, under other circumstances, they may take a different order of arrangement. Thus, at common temperatures, carbonate of ammonia decomposes sulphate of lime; but if a mixture of sulphate of ammonia and carbonate of lime be heated, we obtain carbonate of ammonia and sulphate of lime. The nature of the fluid, in which salts are dissolved, has also an important influence on their tendency to mutual decomposition. (Ann. de Chim. et de Phys., iv., 366.)

Other exceptions to the laws of affinity, affecting double as well as single decompositions, have been classed together under the name of *reciprocal affinity*. They occur chiefly in the mutual action of soluble carbonates and insoluble salts on each other, and are limited to those cases in which an insoluble compound is one of the products. For example, carbonate of potassa and sulphate of baryta, in quantities denoted by their atomic numbers, when long boiled together with water, form carbonate of baryta and sulphate of potassa. Thus,


Sulphate of Potassa (sol.)
Carb. of Potassa, (soluble)
Potassa
Sulph^{c}. Acid
Carb^{c}. Acid
Baryta
Sulphate of Baryta (insol.)
Carb. of Baryta (insol.)

But if we reverse the experiment, and digest together equivalent quantities of sulphate of potassa and carbonate of baryta, we have still a mutual exchange of acids and bases, as follows:



Now the results of the latter experiment would appear, on first view, quite inconsistent with the order of affinities established by the former. But when the facts are closely examined, it will be found that in neither case is the exchange of principles complete; for, in both, the decomposition ceases as soon as the newly-formed compounds have acquired a certain proportion to the original ones and to each other. In the case exhibited by the first diagram, the alkaline energy of the soluble carbonate gradually becomes less as its quantity diminishes; and as the solution approaches nearer and nearer to neutralization. In the second case, the decomposition cannot be carried beyond that point at which the carbonate of baryta and sulphate of potassa, remaining undecomposed, are in certain proportions to each other. These facts have been carefully investigated and ingeniously explained by Dulong, at greater length than would be consistent with the objects of this work. I refer, therefore, to his Memoir in the 82d vol. of the Annales de Chimie, which has been translated into the 35th and 36th vol. of Nicholson's 8vo. Journal, and published in an abridged form in the 41st vol. of the Philosophical Magazine.

SECTION VIII.

Experimental Illustrations of Chemical Affinity, Solution, &c.

For these experiments, a few wine-glasses, or, in preference, deep ale-glasses, will be required; and a Florence flask for performing the solutions.

I. *Some bodies appear to have no affinity for each other.*—Oil and water, mercury and water, or powdered chalk and water, when shaken together in a vial, do not combine, the oil or water always rising to the surface, and the mercury or chalk sinking to the bottom.

II. *Examples of chemical affinity, and its most simple effect, viz., solution.*—Sugar or common salt disappears or dissolves in water; chalk in dilute muriatic acid. Sugar and salt are therefore said to be *soluble* in water, and chalk in muriatic acid. The liquid, in which the solid disappears, is termed a *solvent* or *menstruum.* Chalk or sand, on the contrary, when mixed with water by agitation, always subsides again. Hence they are said to be *insoluble.*

III. *Influence of mechanical division in promoting the action of che-*

mical affinity, or in favouring solution.—Lumps of chalk or marble dissolve much more slowly in dilute muriatic acid, than equal weights of the same bodies in powder. Muriate of lime, or nitrate of ammonia, cast, after liquefaction by heat, into the shape of a solid sphere, is very slowly dissolved; but with great rapidity when in the state of a powder or of crystals. When a lump of the Derbyshire fluate of lime is immersed in concentrated sulphuric acid, scarcely any action of the two substances on each other takes place; but if the stone be finely pulverized, and then mingled with the acid, a violent action is manifested, by the copious escape of vapours of fluoric acid. In the common arts of life, the rasping and grinding of wood and other substances are familiar examples.

IV. *Hot liquids, generally speaking, are more powerful solvents than cold ones.*—To four ounce-measures of water, at the temperature of the atmosphere, add three ounces of sulphate of soda, in powder. Only part of the salt will be dissolved, even after being agitated some time. Apply heat, and the whole of the salt will disappear. When the liquor cools, a portion of salt will separate again in a regular form, or in *crystals*. This last appearance affords an instance of *crystallization*.

To this law, however, there are several exceptions; for many salts, among which is chloride of sodium, or common salt, are equally, or almost equally, soluble in cold as in hot water. Hence, a hot and saturated solution of chloride of sodium, does not, like the sulphate, deposit crystals on cooling. To obtain crystals of the chloride, and of other salts which observe a similar law as to solubility, it is necessary to evaporate a portion of the water; and the salt will then be deposited, even while the liquor remains hot. In general, the more slow the cooling, or evaporation, of saline solutions, the larger and more regular are the crystals.

V. *A very minute division of bodies is effected by solution.*—Dissolve two grains of sulphate of iron in a quart of water, and add a few drops of this solution to a wine-glassful of water, into which a few drops of tincture of galls have been stirred. The dilute infusion of galls will speedily assume a purplish hue. This shows that every drop of the quart of water, in which the sulphate of iron was dissolved, contains a notable portion of the salt.

VI. *Some bodies dissolve much more readily and copiously than others.*—Thus, an ounce measure of distilled water will dissolve half its weight of sulphate of ammonia, one-third its weight of sulphate of soda, one-sixteenth of sulphate of potassa, and only one five-hundredth its weight of sulphate of lime.

VII. *Mechanical agitation facilitates solution.*—Into a wine-glassful of water, tinged blue with the infusion of litmus, let fall a small lump of solid tartaric acid. The acid, if left at rest, even during some hours, will only change to red that portion of the infusion which is in immediate contact with it. Stir the liquor, and the whole will immediately become red.

VIII. *Bodies do not act on each other, unless either one or both be in a state of solution, or at least contain water.*—1. Mix some dry tartaric acid with dry bi-carbonate of soda, and grind them together in a mortar. No combination will ensue till water is added; which, acting the part of a solvent, promotes the union of the acid and alkali, as appears from a violent effervescence. It has been shown by Link, that the water of crystallization, existing in certain salts, acts as free water in occasioning chemical action. For example, acetate of lead and sulphate of copper, both in crystals, become green when triturated together, a proof of the mutual decomposition of those two salts.

2. Spread thinly, on a piece of tinfoil, three or four inches square, some dry nitrate of copper,* and wrap it up. No effect will follow. Unfold the tinfoil, and, having sprinkled the nitrate of copper with the smallest possible quantity of water, wrap the tinfoil up again as quickly as possible, pressing down the edges closely. Considerable heat, attended with fumes, will now be excited; and, if the experiment has been dexterously managed, even light will be evolved. This shows that nitrate of copper has no action on tin, unless in a state of solution.

IX. *Bodies, even when in a state of solution, do not act on each other at perceptible distances;* in other words, contiguity is essential to the action of chemical affinity. Thus, when two fluids of different specific gravities, and which have a strong affinity for each other, are separated by a thin stratum of a third, which exerts no remarkable action on either, no combination ensues between the uppermost and lowest stratum. Into a glass jar, or deep ale-glass, pour two ounce-measures of a solution of subcarbonate of potassa, containing, in that quantity, two drachms of common salt of tartar. Under this introduce, very carefully, half an ounce-measure of water, holding in solution a drachm of common salt; and again, under both these, two ounce-measures of sulphuric acid, which has been diluted with an equal weight of water, and allowed to become cool. The introduction of a second and third liquid, beneath the first, is best effected by filling, with the liquid to be introduced, the dropping tube, fig. 15, plate i.; which may be done by the action of the mouth. The finger is then pressed on the upper orifice of the tube; and the lower orifice, being brought to the bottom of the vessel containing the liquid, the finger is withdrawn, and the liquid descends from the tube, without mingling with the upper stratum. When a solution of carbonate of potassa is thus separated from diluted sulphuric acid, for which it has a powerful affinity, by the intervention of a thin stratum of brine, the two fluids will remain distinct and inefficient on each other; but, on stirring the mixture, a violent effervescence ensues, in consequence of the action of the sulphuric acid on the potassa.

X. *Two bodies, having no affinity for each other, unite by the intervention of a third.*—Thus, the oil and water which, in Experiment I., could not, by agitation, be brought into union, unite immediately on adding a solution of caustic potassa. The alkali, in this case, acts as an intermedium. The fact, however, admits of being explained by the supposition, that the oil and alkali form, in the first instance, a compound which is soluble in water.

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* To prepare nitrate of copper, dissolve the filings or turnings of that metal in a mixture of one part nitrous acid and three parts water; decant the liquor when it has ceased to emit fumes; and evaporate it to dryness, in a copper or earthen dish. The dry mass must be kept in a bottle.

XI. *Saturation and neutralization illustrated.*—Water, after having taken up as much common salt as it can dissolve, is said to be *saturated* with salt. Muriatic acid, when it has ceased to act any longer on lime, is said to be *neutralized*, as is also the lime.

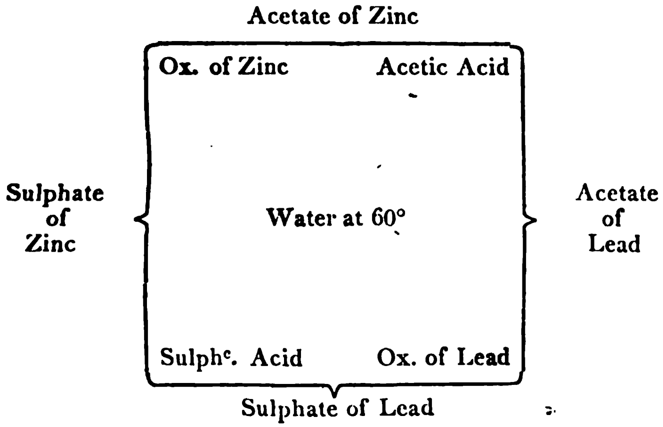
XII. *The properties characterizing bodies, when separate, are destroyed by chemical combination, and new properties appear in the compound.*—Thus muriatic acid and lime, which in a separate state have each a most corrosive taste, lose this entirely when mutually saturated; the compound is extremely soluble, though lime itself is very difficult of solution; the acid no longer reddens syrup of violets, nor does the lime change it, as before, to green. The resulting compound, also, muriate of lime, exhibits new properties. It has an intensely bitter taste; is susceptible of a crystallized form; and the crystals, when mixed with snow or ice, generate a degree of cold sufficient to freeze quicksilver.

XIII. *Single elective affinity illustrated.*—1. Add to the combination of oil with alkali, formed in Experiment X., a little diluted sulphuric acid. The acid will seize the alkali, and set the oil at liberty, which will rise to the top. In this instance, the affinity of alkali for acid is greater than that of alkali for oil. 2. To a dilute solution of muriate of lime (prepared in Experiment II.), add a little of the solution of pure potassa. The potassa will seize the muriatic acid, and the lime will fall down, or be *precipitated.*

XIV. *In some instances, in comparing the affinities of two bodies for a third, a weaker affinity, in one of the two compared, will be found to be compensated by increasing its quantity.*—It is not easy to offer clear and unequivocal examples of this law, and such as the student may submit to the test of experiment. The following, however, may illustrate the proposition sufficiently: Mingle together, in a mortar, one part of muriate of soda (common salt) with half a part of red oxide of lead (litharge, or red lead), and add sufficient water to form a thin paste. The oxide of lead, on examining the mixture after twenty-four hours, will be found not to have detached the muriatic acid from the soda; for the strong taste of that alkali will not be apparent. Increase the weight of the oxide of lead to three or four times that of the salt; and, after the same interval, the mixture will exhibit, by its taste, marks of uncombined soda. This proves, that the larger quantity of the oxide of lead must have detached a considerable portion of muriatic acid from the soda, though the oxide has a weaker affinity for that acid than the soda possesses.

Another illustration of the same general principle has been suggested by Berzelius. It is necessary to premise, that the colour of the compound of sulphuric acid with oxide of copper is blue, and that of muriatic acid with the same oxide, green. To a saturated solution of sulphate of copper in water, add by degrees concentrated muriatic acid. Every addition will render the colour of the liquid more distinctly green, showing an increased production of muriate of copper; the oxide of copper being divided between the sulphuric and muriatic acids, in proportion to the quantity of each acid that is present. In a still greater number of cases, however, a weaker affinity, in one of two bodies compared, cannot be compensated by increasing its quantity. No quantity of tartaric acid, for example, that can be employed, will be found to dislodge sulphuric acid from sulphate of lime.

XV. *Double elective affinity exemplified.*—In a watery solution of sulphate of zinc, immerse a thin sheet of lead: the lead will remain unaltered, as also will the sulphate of zinc, because zinc attracts sulphuric acid more strongly than lead. But let a solution of acetate of lead be mixed with one of sulphate of zinc; the lead will then go over to the sulphuric acid, while the zinc passes to the acetic. The sulphate of lead, being insoluble, will fall down in the state of a white powder; but the acetate of zinc will remain in solution. The changes that occur in this experiment will be better understood from the following scheme:



The vertical brackets include the original compounds, *viz.*, sulphate of zinc, and acetate of lead; and the horizontal line and bracket point out the new ones, *viz.*, acetate of zinc and sulphate of lead. By the upper horizontal line, it is denoted, that the acetate of zinc remains in solution; and, by the point of the lower bracket being directed downwards, it is meant to express, that the sulphate of lead falls down, or is precipitated.

CHAPTER III.

OF HEAT OR CALORIC.

SECTION I.

General Observations on Heat.

When we apply the hand to a body which is hotter than itself, we are sensible of a peculiar feeling, which we agree to call the *sensation of heat*. At the same time we observe, in almost all bodies that are placed in the same situation with the hand, certain effects, the most remarkable of which is an enlargement of their dimensions. These circumstances, with very few exceptions, so constantly accompany each other, that we can have no hesitation in referring them to one and the same cause. Of the nature of this cause we have no satisfactory evidence; and we are unable to demonstrate either that it consists in any general quality of bodies, or that it resides in a distinct and peculiar kind of matter. The opinion, however, which best explains the phenomena, is that which ascribes them to an extremely subtile fluid, of so refined a nature, as to possess no sensible weight, and to be capable of insinuating itself between the particles of the most dense and solid bodies. To this fluid, as well as to the sensation which it excites, the term *heat* was formerly applied. But there was thought to be an obvious impropriety in confounding, under one appellation, two things so distinct as a sensation and its cause; and the term *caloric*, first proposed by Lavoisier, is now frequently adopted to denote the *cause of heat*. Occasionally, however, in order to avoid too frequent a repetition of the same word, the term *heat* is still employed in a more extensive sense, to express not only the sensation which it usually denotes, but also some of the modifications of caloric. And as the context generally shows in which sense the term is to be understood, I shall not scruple to use it in both.

Caloric, so far as its chemical agencies are concerned, may be chiefly considered under two views—as an antagonist to the cohesive attraction of bodies—and as concurring with, and increasing elasticity. By removing the particles of any solid to a greater distance from each other, their cohesive attraction is diminished; and one of the principal impediments to their union with other bodies is overcome. On the other hand, caloric may be infused into bodies in such quantity, as not only to overcome cohesion, but to place their particles beyond the sphere of mutual attraction. Thus, in the class of substances called gases, the *base* or ponderable ingredient, whether solid or liquid, is dissolved in so much caloric, that, with few exceptions, the bases of different gaseous bodies do not unite by simple mixture of the gases themselves. But if of two gases, we employ either one or both in a state of great condensation, the gravitating matter of both unites, and forms a new compound. Hydrogen and nitrogen gases, for example, may be mingled together, in the proportions adapted to form ammonia, without any production of that compound. But if hydrogen, in what has been called its *nascent state* (that is, before it has acquired an atmosphere of heat, and become gaseous), be brought into contact with nitrogen gas, ammonia is then generated. (See chapter viii. sect. i.) In many cases, also, when two bodies are combined together, one of which is fixed, and the other becomes elastic by union with caloric, we are able, by its interposition alone, to effect their disunion. Thus carbonate of lime gives up its carbonic acid by the mere application of heat.

We may consider, then, all bodies in nature as subject to the action of two opposite forces, the mutual attraction of their particles on the one hand, and the repulsive power of caloric on the other; and bodies exist in the solid, liquid, or elastic state, as one or the other of these forces prevails. Water, by losing caloric, has its cohesion so much increased, that it assumes the solid form of ice; adding caloric, we diminish its cohesion, and again render it fluid; and, finally, by a still further addition of caloric, we change it into vapour, and give it so much elasticity, that it may be rendered capable of bursting the strongest vessels. In many liquids, the tendency to elasticity is even so great, that they pass, at common temperatures, to the gaseous form, by the mere removal of the weight of the atmosphere.

Caloric, like all other bodies, may exist in two different states, in a state of freedom, and in a state, either of combination or of something nearly resembling it. In the former state it is capable of exciting the sensation of heat, and of producing expansion in other bodies. To this modification the terms *free* or *uncombined caloric*, or *caloric of temperature*, have been applied. By the term *temperature*, we are to understand the state of a body relatively to its power of exciting the sensation of heat, and occasioning expansion; effects which, in all probability, bear a proportion to the quantity of free caloric in a given space, or in a given quantity of matter. Thus what we call a high temperature may be ascribed to the presence of a large quantity of free caloric; and a low temperature to that of a small quantity. We are unacquainted, however, with the extremes of temperature; and may compare it to a chain, of which a few of the middle links only are exposed to our observation, while its extremities are far removed from our view.

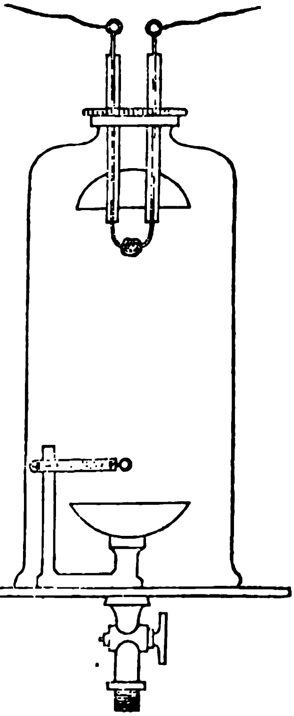
The degree of expansion produced by caloric, it will afterwards appear, bears a sufficient proportion to its quantity, to afford us a means of ascertaining the latter with tolerable, though not perfect, accuracy. In estimating temperature, indeed, our senses are extremely imperfect; for we compare our sensations of heat, not with any fixed or uniform standard, but with those sensations, of which we have had immediately previous experience. The same portion of water will feel warm to one hand removed from contact with snow, and cold to the other hand which has been heated before the fire. To convey, therefore, any precise notion of temperature, we are obliged to describe the degree of expansion produced in some one body, which has been previously agreed upon as a standard of comparison. The standard most commonly employed is a quantity of quicksilver, contained in a glass ball, which terminates in a long narrow tube. This instrument, called a *thermometer*, is of the most important use in acquiring and recording our knowledge of the properties and laws of caloric. The thermometer, however, it must be obvious, is no otherwise a measurer of the quantity of caloric, than as it ascertains the amount of one of its principal effects. In this respect, it stands in much the same predicament as the hygrometers of Saussure or Deluc, when considered as means of determining the moisture of the atmosphere. These last instruments, it may be remembered, are composed of some substance (such as a human hair, or a slip of whalebone) which is lengthened by a moist atmosphere, and contracted by a dry one; and in a degree proportionate to the moisture or dryness. But all the information, which hygrometers of this sort give us, is the degree of moisture between certain points that form the extremities of th[illegible]cales; and they are quite incompetent to measure the absolut[illegible]ntity of watèry vapour in the air.

In explaining those properties and laws of caloric, which have become known to us by means of the thermometer, it appears a sufficiently natural division of the subject to describe, 1stly, those effects which caloric produces, without losing its properties of exciting the sensation of heat and occasioning expansion: and, 2dly, those agencies, in which its characteristic properties are destroyed, and in which it ceases to be cognizable by our senses or by the thermometer.

I. The EXPANSION OR DILATATION of bodies, it will appear, is an almost universal effect of an increase of temperature. Its amount, however, is not the same in all bodies, but differs very essentially. By the same increase of temperature, liquids expand more than solids, and aëriform bodies much more than either. Nor is the same quantity of expansion effected in the *same* solid or liquid, at all temperatures, by adding similar quantities of heat; for, generally speaking, bodies expand by equal increments of caloric, more in high than in low temperatures. The explanation of this fact is, that the force opposing expansion (*viz.* cohesion) is diminished by the interposition of caloric between the particles of bodies: and, therefore, when equal quantities of caloric are added in succession, the last portions meet with less resistance to their expansive force than the first. In gases, which are destitute of cohesion, equal increments of heat appear, on the contrary, to be attended with precisely equal augmentations of bulk.

An important property of free caloric, the knowledge of whic[illegible] has been acquired by means of the thermometer, is its *tendency* [illegible] *an equilibrium*. Twenty or thirty different bodies, for instance, [illegible] unequally heated, soon arrive, when exposed in a still atmosphere, at an equality of temperature. When a heated ball of iron is exposed to the open air, the caloric, which is accumulated in it, flows out; and the temperature of the ball is gradually reduced to that surrounding medium. This is owing to two distinct causes; r, immediately surrounding the ball, acquires part of the ca- which escapes; and, having its bulk increased, is rendered spe- ly lighter, and ascends. This is succeeded by a cooler and r portion of air from above, which in its turn is expanded, arries off a second quantity of caloric. Hence a consider- art of the caloric, which is lost by a heated body, is con- away by the ambient air; a property, of which advantage is in the warming and ventilating of apartments. But the re- ition cannot be wholly explained on this principle; for it has ong known that heated bodies cool, though with less celerity, the exhausted receiver of an air-pump, and even in a Torri- vacuum.

ien the phenomena accompanying the cooling of bodies are itely examined, it is found that a part of the caloric, which s, moves through the atmosphere with immeasurable ve- In an experiment of M. , no perceptible interval took between the time at which quitted a heated body, and eption by a thermometer at stance of sixty-nine feet. It rs also, from the experiments same philosopher, to move equal ease in all directions, ot to be at all diverted from irse by a strong current of eting it transversely. Hence ws that the propagation of , in this state of rapid move- does not depend on any of the medium through it passes. This was satis- ly proved by Sir. H. Davy, ntrived by means of the ap- s, represented in the annex- tch, to effect the radiation at *in vacuo*. Between the of two wires, enclosed in ubes, which passed through plate, was placed a piece rcoal, which was intensely l by voltaic electricity, and ect of radiation in the focus lower concave mirror was ined by a delicate thermo- , first when the receiver was full of air, and next when it was sted to $\frac{1}{120}$. In the latter case, the effect of radiation was to be three times greater than in an atmosphere of common y. The greater rise of the thermometer in vacuo than in air e ascribed to the conducting power of the latter; for this



conducting power, by reducing the temperature of the heated body, has a constant tendency to diminish the activity of radiation, which is always proportional to the excess of temperature of the heated body above that of the surrounding medium.

Like light, heat appears to be transmitted in parallel rays, and when thus in motion, it has been called RADIANT CALORIC. The comparative quantities of caloric, lost by radiation and by conduction, may be approximated by observing what time a body takes to cool, through the same number of degrees, in air and in vacuo. By experiments of this kind, Dr. Franklin thought he had ascertained that a body, which requires five minutes in vacuo, will cool in air, through the same number of degrees, in two minutes. Count Rumford's experiments with a Torricellian vacuum give the proportions of 5 in vacuo, to 3 in air. It will, perhaps, not be very remote from the truth, if it be stated, in general terms, that one-half of the caloric, lost by a heated body, escapes by radiation, and that the rest is carried off by the ambient atmosphere.

The rate of cooling in air appears to bear a proportion to the elevation of temperature of a body above that of the surrounding medium. Hence in part it is, that a heated body, during refrigeration, loses unequal quantities of caloric in equal times. The series makes some approach to a geometrical one. Thus, supposing the temperature of a body to be 1000 degrees above the surrounding medium,

In the first minute it will lose - - $\frac{9}{10}$ of its heat or 900°
In the second - - - - - - $\frac{9}{10}$ of the remainder $=90$
In the third - - - - - - $\frac{9}{10}$ of 10 - - $=9$

This law of refrigeration, originally laid down by Newton, though nearly accurate at low temperatures, it has been shown by Delaroche, is far from being so at high ones; and his objections have been fully confirmed by Petit and Dulong, who have proved that the error increases as the temperature augments, and at length becomes enormously great. (Annals of Philosophy, vol xiii.)

The movement of caloric by radiation occurs only in free space, or through transparent media. It appears to be the same through all the different varieties of aëriform bodies; though, as will afterwards appear, the gases differ materially from each other in their *conducting power*. Caloric radiates from bodies at all temperatures, but the quantity radiated in a given time bears some proportion to the excess of the temperature of the hot body above that of the surrounding medium. So also does its *intensity* or *tension*, for the higher the temperature of its source, the more readily does radiated caloric penetrate glass and other transparent bodies. And if we have any number of bodies at different temperatures in the vicinity of each other, they may all, agreeably to the ingenious theory of M. Prevost, be considered both as radiating and receiving caloric; but the hot ones will radiate more than they receive, while the cold ones will receive more than they radiate.

The process of radiation appears to be constantly going on from the surface of the earth, and it is partly on this principle that we are to explain why the heat, which our planet is incessantly receiving from the sun, does not accumulate to such a degree as to render it a less fit habitation for man. The period, when radiation from the surface of the globe is most discoverable by its effects, seems to be during the night, especially when the sky is perfectly unclouded; for a covering of clouds serves as a mantle to the earth, which not only prevents the free escape of radiant heat, but probably radiates it back to the earth's surface. Under favourable circumstances, it has been shown by Dr. Wells, that the temperature of the ground, especially when its covering is formed of some substance that radiates freely, is several degrees below that of the atmospheric stratum, a few feet above it. It is this diminished temperature of the earth's surface, that occasions the deposition of dew and hoar frost, which are always observed to be most abundantly formed under a clear unclouded sky.

Caloric, besides radiating through transparent media, is capable, also, of passing through dense and opaque bodies, though with prodigiously impaired velocity. Thus a long bar of iron, heated at one end, requires considerable time to become hot at the other. This property in bodies has been called their CONDUCTING POWER, and it exists, in different bodies, in very different degrees. It is not, however, found to bear a proportion to any other quality of bodies, such as their densities, &c.

II. All the properties of caloric, which have been hitherto described, belong to it when supposed to be in a free or uncombined form; for it continues to produce the sensation of heat, and to expand the mercury of the thermometer. In the instances of its agency, also, that have been mentioned, no permanent change of form or of properties is effected in the bodies which have imbibed caloric. A bar of iron, after being expanded by heat, returns on cooling to the same state as before, and exhibits all its former qualities. In certain cases, however, caloric is absorbed by bodies, with the loss of its distinguishing properties. It can then be no longer discovered by our senses or by the thermometer; and it produces important and sometimes permanent changes in the bodies into which it enters.

Those effects of caloric, in the production of which it loses its distinguishing properties, may be classed under two general heads.

1. *Bodies, in passing from a denser to a rarer state, generally absorb caloric.*—Thus solids, during liquefaction, imbibe a quantity of caloric, which ceases to be apparent to our senses or to the thermometer; or, as it has been termed, *becomes latent.* In a similar manner, solids and liquids, during their conversion into vapours or gases, render latent a quantity of caloric, which is essential to the elasticity of the new product. In common language cold is, in such cases, said to be produced; but by the production of cold we are to understand, in philosophical language, nothing more than the passage of caloric from a free to a latent form.

2. *Bodies, by an increase of density, mostly evolve or give out caloric, which passes from a latent to a free state.*—The simplest illustration of this law is in the effect of hammering a piece of metal, which may thus be intensely heated, while all that is permanently

effected is an augmentation of its density. Liquids by becoming solids, or gases by conversion into liquids, also, evolve caloric, or produce an increase of temperature. A pound of water condensed from steam, will render 100 pounds of water at 50° warmer by 11°; whereas a pound of boiling water will produce the same rise of temperature in no more than about 13½ pounds. This is owing to the much greater quantity of caloric, existing in a pound of steam, than in a pound of boiling water, though steam and boiling water affect the thermometer in precisely the same degree.

It is a question which has excited considerable interest among philosophers, whether caloric, when thus absorbed and rendered latent, enters into chemical combination, or is merely united by the same kind of ties as that portion of caloric that produces the temperature of bodies. Does ice, for example, when changed into water, form a chemical union with caloric, similar to that which exists between potassa and sulphuric acid? Such appears to have been the opinion of Dr. Black, who, by the powers of an original and well-directed genius, discovered, about the year 1760, the greater number of those facts, that formed the ground-work of the theory of latent heat. The resemblance, however, between chemical union and the disappearance of caloric, which, on first view, appears extremely striking, will be found, it must be confessed, less close on a nearer examination; for caloric may be made to quit those bodies, into which it has entered with a loss of its peculiar properties, merely by reducing their temperature; whereas chemical combinations in general cannot be destroyed, except by the interference of more energetic affinities. In opposition to the foregoing theory, it has been contended that the absorption of caloric by bodies is a consequence of what has been called a change of their *capacity*. Thus ice, it is supposed, in becoming water, has its capacity for caloric increased, and the absorption of caloric is regarded as a consequence of this increased capacity. This theory, however, is deficient, inasmuch as it fails to explain what is the cause of that change of form, which is assumed to account for the increase of capacity. Notwithstanding this obvious objection, I have retained the term *capacity* to express, in the abstract, that power by which bodies absorb and render latent different quantities of caloric; or the property of requiring more or less caloric for raising their temperature an equal number of degrees. The absorption of caloric, then, will always be owing to an increase, and its evolution to a decrease, of capacity. The use of these terms may be exemplified by a slight change of the perspicuous language of Dr. Crawford. "The capacity for containing caloric," he observes, "and the absolute caloric contained, are distinguished as a force from the subject upon which it operates. When we speak of the *capacity*, we mean a power inherent in the heated body; when we speak of the *absolute caloric*, we mean an unknown principle, which is retained in the body by the possession of this power; and when we speak of the *temperature*, we consider the unknown principle as producing certain effects upon the thermometer." (Dr. Crawford on Heat, p. 8.)

As the capacities of bodies determine their relative quantities of caloric, it seems reasonable to conclude that, if we can ascertain how much caloric a body absorbs or gives out in changing its form, and in what proportion its capacity is at the same time altered, we may deduce the *absolute quantity of heat* which it contains. Now it will be afterwards shown that the heat, evolved by water in freezing, is equal to 140°; and the capacity of water has been stated to bear to that of ice the proportion of 10 to 9. Water, then, in becoming ice, must give out $\frac{1}{10}$th of its whole caloric, and, as this amounts to 140°, ten times 140 (or 1400°) is the whole quantity of caloric in water at the temperature of 32°; and, deducting 140 from 1400, we have 1260° for the caloric contained in the ice itself. This method of determining the problem seems, however, to me, to be liable to several objections, which it would take up too much room to state in this place, and which I have elsewhere urged at considerable length. (Manchester Memoirs, vol. v.) Nor does it appear to me that any other mode of investigation yet proposed is capable of giving us approximations to the truth, that are more to be relied on; for such enormous differences as to the *absolute zero*, or point of total privation of heat on the thermometric scale, have resulted from the inquiries of different philosophers, as to show that we still want the data essential to such an investigation.

These general observations I have deemed it necessary to make, with a view of connecting together the propositions respecting caloric, and the experiments illustrating them, that form the subject of the following sections. The inquiry respecting heat is one which presents a boundless field for interesting speculation; and it would have been easy to have extended very considerably the discussion of its nature and properties. But, in this work, I have no farther object than to lead the student, by easy steps, to a knowledge of what has been actually determined by experiment, or strictly and legitimately deduced from it.

SECTION II.

Illustrations of the Effects of Free Caloric.

I. *Caloric expands all bodies.*—The expansion of *liquids* is shown by that of the mercury of a thermometer, or by immersing in hot water a glass matrass (pl. i. fig. 4), filled, up to a mark in the neck, with spirit of wine, tinged with any colouring substance. The spirit expands immediately when heated, and would overflow if not placed in a cooler situation. The degree of expansion produced in different liquids, by similar elevations of temperature, varies very considerably. Thus water expands much more than mercury, and alcohol more than water. This difference of expansibility is even sufficiently striking to appear in a remarkable degree when we immerse, in water heated to 150°, three equal glass vessels of the shape of thermometer tubes, containing, the one mercury, the other water, and the third spirit of wine. The spirit will begin to escape from the aperture of the vessel, before the mercury has ascended far in the stem.

It must be obvious, however, that we cannot determine, in this way, the true amount of expansion in any fluid, because the containing glass vessel has, at the same time, its capacity enlarged. Hence the real expansion of the fluid exceeds the apparent; and, in order to know the true amount of expansion in the liquid, we must correct the experimental result by taking into account the expansion of glass. In determining the dilatation of mercury, MM. Petit and Dulong avoided the necessity of this correction, and followed a method founded upon a hydrostatical principle, *viz.*, that when two columns of liquid communicate by a horizontal tube, the vertical heights of their surfaces are in the inverse ratio of their densities. Surrounding, therefore, one of the columns with ice, and raising the other to any known temperature, it was found to be sufficient, in order to obtain the absolute dilatation, to measure the height of each column. (Ann. Ch. et Ph., xvii., or Ann. of Phil. 2d series, vol. 13.)

In the appendix to vol. ii. tables will be found, showing the expansion of various liquids by heat.

The expansion of *aëriform bodies* may be exemplified by holding near the fire a bladder half filled with air, the neck of which is closely tied, so as to prevent the enclosed air from escaping. The bladder will soon be fully distended, and may even be burst by continuing and increasing the heat. All aëriform bodies, when deprived of moisture, and even condensable vapours, when not in contact with the liquids from which they have been produced, undergo the same expansion or contraction, at all temperatures hitherto tried, by similar additions or subtractions of heat. This, for a single degree of Fahrenheit's thermometer, is $\frac{1}{481}$ part of their bulk, between 32° and 212°, as first determined by Mr. Dalton, and afterwards confirmed by Gay Lussac, and by Petit and Dulong, who have extended the law up to 572° Fahr. (An. of Phil., N. S., xiii. 117.) This equable expansion of air by equal increments of heat adapts it for the accurate measurement of temperature. At a cherry-red heat (= about 1035° Fahr.) Sir H. Davy found that a volume of air = 1 at 212° Fahr., became 2.5 volumes. (On Flame, p. 68.)

The expansion of *solids* may be made apparent by heating a rod of iron, of such a length as to be included, when cold, between two points, and the diameter of which is such as barely to allow it to pass through an iron ring. When heated, it will have become sensibly longer; and it will be found incapable of passing through the ring. This property of metals has been applied to a variety of useful purposes. The iron band, or *tire*, as it is called, of a carriage-wheel, being purposely made a little smaller than the wooden circle, is enlarged by heat so as to embrace the latter, and being then suddenly cooled, by throwing water upon it, is again contracted, and becomes immoveably fixed. An ingenious use of the same principle was made, several years ago, at Paris, by M. Molard, in restoring to the perpendicular two opposite walls of a building, which had been pressed outwards by the incumbent weight. Through holes in the walls, opposite to each other, several strong iron bars were introduced, so as to cross the apartment, and to project outside the building sufficiently to allow strong iron plates, or *washers*, to be screwed upon their ends. The bars were then heated, and the iron plates screwed up. On cooling, the bars contracted, and drew the separated walls nearer together; and this was repeated till the walls had regained their perpendicular position.

The expansion of metals produces important effects in various mechanical instruments, especially in clocks; for a pendulum vibrating seconds will, by a change of temperature equal to 30° Fahr. alter its length about $\frac{1}{5000}$ part, which is sufficient to change its rate of going eight seconds of time per day. To obviate this inconvenience, various contrivances have been resorted to, which are described in works on practical horology.

The degree of expansion is not the same for all solids, and even differs materially in substances of the same class. Thus, the metals expand in the following order, the most expansible being placed first: zinc, lead, tin, copper, bismuth, iron, steel, antimony, palladium, platinum. The experiments of Petit and Dulong (Ann. of Phil., xiii. 164) tend to show that unequal degrees of expansion are produced in a bar of metal by a succession of similar increments of heat; the rate of expansion increasing with the temperature, as appears from the following table:

Tempᵗ. measured by expansion of air.	Expansions in bulk of			Linear expansions.		
	Iron.	Cop.	Plat.	Iron.	Cop.	Plat.
0° to 100° cent. give	$\frac{1}{282}$	$\frac{1}{193}$	$\frac{1}{377}$	$\frac{1}{846}$	$\frac{1}{582}$	$\frac{1}{1131}$
0° to 300° cent. (mean)	$\frac{1}{227}$	$\frac{1}{177}$	$\frac{1}{363}$	$\frac{1}{681}$	$\frac{1}{531}$	$\frac{1}{1089}$

The instrument by which different expansions are measured is called a *pyrometer*, and, in its construction, so as to render it capable of measuring very small dilatations, great ingenuity has been exerted by various philosophers and artists. The results of the most accurate experiments on this subject will be found in tables in the appendix. For short distances, these dilatations may not be important, but, in long chains or rods of metal, the amount is considerable. The word *pyrometer* is applied also, not unfrequently, to an instrument adapted to measure, by the expansion of solids, degrees of heat much higher than those which can be determined by the mercurial thermometer. Of these there are several, but the best, perhaps, is that of Mr. Daniel. A bar of platinum is enclosed in a case made of the same ware as black-lead crucibles, and is fixed to it at one end, while the other is left free to move an index, by which means degrees of heat above ignition admit of being measured, but not with accuracy, owing to the increasing rate of expansion in metals at high temperatures. (Jour. of Science, xi. 309.)

On the same principle, M. Bréguet has constructed a very sensible metallic thermometer, for temperatures between the freezing and boiling points of water. (Ann. de Chim. et de Phys., v. 312.)

It consists of a slip of silver and another of platina, united face to face with solder, and coiled into a spiral, one end of which is fixed, while the other is connected with an index which moves over a circular graduated plate. Strictly, two metals only are sufficient for the purpose, platina and silver for instance; but it has been found to be an improvement to employ three, and the instrument is now prepared by interposing between the platina and silver a metal of mean dilatability, such as pure gold. The unequal expansion of the metals causes the spiral to increase or diminish the degree of its curvature by variations of temperature; and the needle, being attached at right angles to the axis of the spiral, is thus made to traverse the graduated circle. Experiment has shown that the needle, for equal changes of temperature, moves over equal arcs, so that the instrument is comparable, not only with itself, but with others constructed on the same principle. Such was found to be its great sensibility, that, when enclosed in a large receiver, which was rapidly exhausted by the air-pump, it indicated a reduction of temperature from 66° Fahr. to 25° (= 41°), while a sensible mercurial thermometer, similarly situated, fell only 3.6°.

To the general law of the expansion of bodies by heat, and their contraction by cold, there are, however, several exceptions. Water by freezing is considerably increased in bulk; salts in the act of crystallizing expand; and some of the metals, as cast-iron, bismuth, and antimony, have their dimensions enlarged by congealing; but mercury and other metals follow the general law, and occupy less bulk when solid than when fluid.

II. *Construction of the thermometer, founded on the principle of expansion.*—The thermometer is an instrument of so much importance, that it may be expedient to trace its history, and to explain the construction of the different kinds which are required in chemical researches.

The instrument employed by Sanctorio, to whom the invention of the thermometer is generally ascribed, was of a very simple kind, and measured variations of temperature by the variable expansion of a confined portion of air. To prepare this instrument, a glass tube (pl. i. fig. 9) is to be provided, eighteen inches long, open at one end, and blown into a ball at the other. On applying a warm hand to the ball, the included air expands, and a portion is expelled through the open end of the tube. In this state, the aperture is quickly immersed in a cup filled with any coloured liquid, which ascends into the tube as the air in the ball contracts by cooling. The instrument is now prepared. An increase of temperature forces the liquor down the tube; and, on the contrary, the application of cold causes its ascent. These effects may be exhibited alternately by applying the hand to the ball, and then blowing on it with a pair of bellows. By the application of a graduated scale, the amount of the expansion may be measured.

The ball of the above instrument, it must be obvious, cannot be conveniently applied to measure the temperature of liquids. For adapting it to this purpose, a slight variation may be made in its construction, as represented fig. 8, *a*. To prepare this instrument, a small spherical glass vessel is to be about one 6th or one 4th filled with any coloured liquid. The tube, open at both ends, is then to be cemented into the neck, with its lower aperture beneath the surface of the fluid. The expansion of the included air drives the liquid up the stem, to which we may affix a graduated scale, corresponding with that of a common mercurial thermometer. Other modifications have also been made by different philosophers. One of the most useful and simple forms is represented fig. 8, *b*. It consists merely of a tube of very small bore, from 9 to 12 inches long, at one end of which is blown a ball, from half an inch to an inch in diameter, which is afterwards blackened by paint, or by the smoke of a candle. A small column of coloured liquid, about an inch in length, is then introduced, by a manipulation similar to that already described. To fit the instrument for use, this column ought to be stationary, about the middle of the tube, at the common temperature of the atmosphere. The slightest variation of temperature occasions the movement of the coloured liquid; and a scale of equal parts measures the amount of the effect.

An insuperable objection, however, to the air thermometer, *as thus constructed*, is, that it is affected not only by changes of temperature, but by variations of atmospheric pressure. Its utility consists in the great amount of the expansion of air, which, by a given elevation of temperature, is increased in bulk above twenty times more than mercury. Hence it is adapted to detect minute changes, which the mercurial thermometer would scarcely discover; and, its expansions being uniform for equal additions of heat, it is better adapted than any liquid for becoming, when properly applied, an accurate measure of temperature.

An ingenious modification of the air thermometer has been invented by Mr. Leslie, and employed by him, with great advantage, in his interesting researches respecting heat. To this instrument he has given the name of the Differential Thermometer. Its construction is as follows: "Two glass tubes of unequal length, each terminating in a hollow ball, and having their bores somewhat widened at the other ends (a small portion of sulphuric acid, tinged with carmine, being introduced into the ball of the longer tube,) are joined together by the flame of a blow-pipe, and afterwards bent nearly into the shape of the letter U (see fig. 7), the one flexure being made just below the joining, where the small cavity facilitates the adjustment of the instrument. This, by a little dexterity, is performed by forcing, with the heat of the hand, a few minute globules of air from the one cavity into the other. The balls are blown as equal as the eye can judge, and from four-tenths to seven-tenths of an inch diameter. The tubes are such as are drawn for thermometers, only with wider bores; that of the short one, to which the scale is affixed, must have an exact calibre of a 50th, or a 60th, of an inch. The bore of the long tube need not be so regular, but should be visibly larger, as the coloured liquid will then move quicker under any impression. Each leg of the instrument is from three to six inches in height, and the balls are from two to four inches apart.

"A moment's attention to the construction of this instrument will satisfy us, that it is affected only by the *difference* of heat in the corresponding balls; and is calculated to measure such difference with peculiar nicety. As long as both balls are of the same temperature, whatever this may be, the air contained in both will have the same elasticity, and, consequently, the intercluded coloured liquor, being pressed equally in opposite directions, must remain stationary. But if, for instance, the ball which holds a portion of the liquor be warmer than the other, the superior elasticity of the confined air will drive the liquid forwards, and make it rise, in the opposite branch, above the zero, to an elevation proportional to the excess of elasticity, or of heat." The amount of the effect is ascertained by a graduated scale, the interval between freezing and boiling being distinguished into 100 equal degrees. This instrument, it must be obvious, cannot be applied to measure variations in the temperature of the surrounding atmosphere, for the reason already assigned. It is peculiarly adapted to ascertain the difference of the temperatures of two contiguous spots in the same atmosphere; for example, to determine the heat in the focus of a reflector.

A differential thermometer has been contrived by Dr. Howard, resembling that of Mr. Leslie in its general form, but in which the degree of heat is measured by the expansive force of the vapour of ether or spirit of wine *in vacuo*. Directions for constructing it are given in the 8th volume of the Quarterly Journal of Science, p. 219. It is intended to be applied to the same purposes as that of Mr. Leslie, but is said to be more sensible to changes of temperature, and the movement of the fluid (ether tinged by a drop of tincture of cochineal) follows instantaneously the application of the heating cause, whereas in the air thermometer some time is required before the effect takes place.

Thermometers, filled with spirits of wine (a liquid which has not been congealed by any degree of cold hitherto produced), are best adapted to the measurement of very low temperatures, at which mercury would freeze. The amount of the expansion of alcohol, also, which exceeds that of mercury above eight times, fits it for ascertaining very slight variations of temperature. But it cannot be applied to measure high degrees of heat; because the conversion of the spirit into vapour would burst the instrument.

The fluid best adapted for filling thermometers is mercury, which, though it expands less in amount than air, or alcohol, still undergoes this change to a sufficient degree; and, in consequence of its difficult conversion into vapour, may be applied to the admeasurement of more elevated temperatures. As a considerable saving of expense will accrue to the experimentalist, who is able to construct mercurial thermometers, I shall offer some rules for this purpose. In general, however, I should deem it preferable merely to superintend their construction, when wanted for delicate experiments, and to be satisfied, by actual inspection, that the necessary accuracy is observed; because much time must be unavoidably lost in acquiring the manual skill which is essential to construct them neatly.

Thermometer tubes may be had at the glass-house, and of most philosophical instrument makers. In purchasing them, those should be rejected that are not hermetically sealed at both ends; because the smallest condensation of moisture, which must take place when air is freely admitted within the tube, is injurious to the accuracy of the instrument. A small bottle of elastic gum should be provided, in the side of which a brass valve is fixed, or a piece of brass perforated by a small hole, to be occasionally stopped by the finger. A blow-pipe is also an essential part of the apparatus; and, in addition to one of the ordinary kind, it will be found useful to have one which is supplied with air by a pair of double bellows, worked by the foot.

Before proceeding to the construction of the thermometer, it is necessary to ascertain that the tube is of equal diameter in different parts. This is done by breaking off both of the sealed ends, immersing one of them an inch or two deep in clean and dry mercury, and then closing the other end with the finger. On withdrawing the tube from the mercury, a small column of that fluid remains in it, the length of which is to be examined, by laying the tube horizontally on a graduated ruler.* By inclining the tube, this column may be gradually moved through its whole length; and if the tube be of uniform bore, it will measure the same in every part. Such a degree of perfection, however, is scarcely ever to be observed throughout tubes of considerable length; but, in general, a portion of the tube will be found perfect, of sufficient length for a thermometer, and this part is to be broken off.

On one end of the tube let the neck of the elastic bottle be firmly tied; and let the other end be heated by the flame of the blow-pipe, till the glass softens. The softened part must then be pressed, by a clean piece of metal, into the form of a rounded button; and to this the flame of the lamp must be steadily applied, till it acquires a white heat, and seems about to enter into fusion. To prevent its falling on one side, the tube, during this time, must be constantly turned round by the hand. When the heated part appears perfectly soft, remove it quickly from the lamp, and, holding the tube vertically, with the elastic bottle uppermost, press this last gently with the hand. The glass will be blown into a small ball, but not into one sufficiently thin for the purpose. To this the flame of the lamp must again be applied, turning it quickly round; and, on a second or third repetition of the process of blowing, the ball will be completely formed. The proportion of the size of the ball to the bore of the tube can only be learned by some experience.

To fill the ball, which has been thus formed, with mercury, the air must first be expelled by holding it over the flame of an Argand's lamp, and then quickly immersing the open end of the tube in very clean and dry quicksilver. As the ball cools, the mercury will ascend, and will partly fill it. Let a paper funnel be tied firmly over the open end of the tube; into this pour a small portion of quicksilver, and apply the heat of the lamp to the ball. Any remaining portion of air will thus be expelled; and if the heat be raised so as to boil the mercury, the ball and stem will be filled with mercurial vapour, the condensation of which, on removing the ball from the lamp, will occasion a pretty complete vacuum. Into this vacuum, quicksilver will descend from the paper cone; and the instrument will be completely filled. But, for the purpose of a thermometer, it is necessary that the mercury should rise only to a certain height in the stem; and a few drops may, therefore, be expelled by cautiously applying the heat of the lamp. To estimate whether the proper quantity of quicksilver has been left in the instrument, immerse the ball first in ice-cold water, and then the mouth. The space between these two points will comprise about 64°, or rather more than one-third of the whole space between the freezing and boiling points of water. If the empty part of the tube exceeds, in length, about three times the portion thus filled by the expanded quicksilver, we may proceed (when an instrument is wanted with a scale including only from 32° to 212°) to seal it hermetically, which is done as follows: The part to be sealed is first heated with the blow-pipe, and drawn out to a fine capillary tube; the bulb is then heated, till a few particles of quicksilver have fallen from the top of the tube: at this moment, the flame of another candle is directed, by the blow-pipe, on the capillary part of the tube, the candle is withdrawn from the ball, and the tube is sealed, at the instant when the mercury begins to descend. If this operation has been skilfully performed, so as to leave no air in the tube, the whole of the tube should be filled with quicksilver on holding the instrument with the ball uppermost.

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* If the tube be of an extremely small bore, the mercury will not enter, and must be drawn in by the action of the elastic bottle, and not by the mouth.

To have very large degrees, the ball must bear a considerable proportion to the tube; but this extent of scale cannot be obtained without sacrificing, in some measure, the sensibility of the instrument.* The whole of the process of constructing thermometers neatly and accurately is connected with the possession of manual skill, which practice only can confer; and it is scarcely possible, without the most tedious minuteness, to describe all the necessary precautions and manipulations. These will readily suggest themselves to a person who carries the above instructions into effect.

In graduating thermometers, the first step consists in taking the two fixed points. The freezing point is ascertained, by immersing, in thawing snow or ice, the ball and part of the stem; so that the mercury, when stationary, shall barely appear above the surface. At this place let a mark be made with a file. In taking the boiling point, considerable caution is required; and, for reasons which will afterwards be stated, attention must be paid to the state of the barometer, the height of which, at the time, should be precisely 29.8. A tin vessel is to be provided, (for, according to Gay Lussac,† one of glass leads to erroneous results,) four or five inches longer than the thermometer, and furnished with a cover, in which are two holes. Through one of these the thermometer stem must be passed (the bulb being within the vessel), so that the part at which the boiling point is expected may be just in sight. The other hole may be left open; and, the cover being fixed in its place, the vessel, containing a few inches of water at the bottom, is to be set on the fire. The thermometer will presently be wholly surrounded by the steam; and when the mercury becomes stationary in the stem, its place must be marked. The scale of Fahrenheit is formed by transferring the intermediate space to paper by a pair of compasses, and dividing it into 180°, the lowest being called 32°, and the highest 212°. The scale of other countries, however, differs considerably; but these variations do not prevent the comparison of observations with different instruments, when the freezing and boiling points of water are agreed upon as fixed data. In the Appendix, rules will be given for converting the degrees of other scales to that of Fahrenheit.

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* Directions for constructing thermometers of great sensibility are given by the Chevalier Landriani, in the 7th volume of the Journal of Science, p. 183.

† 82 An. de Ch. 174, and 7 An. de Ch et de Phys. 307.

III. *The dilatations and contractions of the fluid in the mercurial thermometer, are nearly proportional to the quantities of caloric, which are communicated to the same homogeneous bodies, or separated from them, so long as they retain the same form.*

Thus the quantity of caloric required to raise a body 20° in temperature, by the mercurial thermometer, is *nearly* double that which is required to raise it 10°. Hence there appears to be a pretty accurate proportion between the increments or decrements of heat, and the increments or decrements of expansion in the mercury of a thermometer. On this principle, if equal quantities of hot and cold water be mixed together, and a thermometer be immersed in the hot water, and also in the cold, previously to the mixture, the instrument should point, after the mixture, to the arithmetical mean, or to half the difference of the separate heats, added to the less, or subtracted from the greater. This will be proved to be actually the fact, by the following experiment. Mix a pound of water at 172° with a pound at 32°. Half the excess of the caloric of the hot water will pass to the colder portion; that is, the hot water will be cooled 70°, and the cold will receive 70° of temperature; therefore 172 — 70, or 32 + 70 = 102, will give the heat of the mixture. To attain the arithmetical mean exactly, several precautions must be observed, which have been pointed out in Dr. Crawford's Essay on Heat, p. 95.

The experiments of De Luc, however, have shown, that the ratio of expansion does not, *strictly*, keep pace with the actual increments of temperature; and that the amount of the expansion increases with the temperature. Thus if a given quantity of mercury, in being heated from 32 to 122°, the first half of the scale, be expanded 14 parts, in being raised from 122 to 212°, the higher half, it will be expanded 15 parts.

From the inquiries of Mr. Dalton, it appears to follow, that the irregularity of the expansion of mercury is even considerably greater than has been stated by De Luc. By the common mercurial thermometer, we cannot ascertain the true rate of expansion in quicksilver; since the enlarged capacity of the glass ball, in which the fluid is contained, must necessarily affect the result. If the capacity of the ball remained unaltered, we should then be able to determine the actual rate of expansion; but by an increase of temperature its capacity is enlarged, and space is thus found, within the ball, for the expansion of that mercury, which would otherwise be driven into the tube. By knowing the rate of expansion in glass itself, we can correct this error; but a small mistake in this datum will lead us considerably wrong as to the true expansion of quicksilver. The *real* expansion of mercury in glass is *greater* than the *apparent*, by the expansion of the glass itself.

Making due correction for this circumstance, Mr. Dalton was led to conclude, from his experiments, that notwithstanding the apparent diversities of expansion in different fluids, they all actually expand according to the same law, *viz.*, *that the quantity of expansion is as the square of the temperature from their respective freezing points, or from their points of greatest density.* If then a thermometer were constructed, with degrees corresponding to this law, they would be found to differ very considerably from those of the common mercurial thermometer, in which the space between freezing and boiling is divided into 180 equal parts. But the accuracy of the principle, on which this proposed modification of the thermometric scale is founded, has not been confirmed by subsequent experience.

The view which has been taken by Mr. Dalton of the thermometer, has drawn the attention of Dr. Ure[*] and of MM. Petit and Dulong,[†] to the same subject. The former concludes, from his experiments, that taking three thermometric intervals from 32° Fahr. upwards, each of 180°, mercury has actually an increasing rate of expansion, and that 60 parts at 572° are expanded as much by the same power of caloric, as 61 parts at 392°, and 62 parts at 212°. But this small difference, he observes, is compensated by the lessening quantity of quicksilver in the bulb of a thermometer at high temperatures, in consequence of which the mercurial thermometer becomes a true measurer of sensible heat. Petit and Dulong, also, satisfied themselves that the expansibility of mercury slowly increases as the temperature augments. From —40° to 212°, it is scarcely appreciable, and corresponds with the expansion of air, which they take for granted to be perfectly equable. The following Table exhibits the dilatation of mercury for a degree centigrade at the various temperatures (all centigrade[‡]) indicated in the first column of the table, and measured by an air thermometer.

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[*] Phil. Trans. 1818.

[†] Annals of Philos. vol. xiii.

[‡] To convert centigrade degrees into those of Fahr., double them, then deduct one-tenth, and add the constant number 32. Thus 18° centigrade × 2 = 36, from which $\frac{1}{10}$ substracted leaves 32.4, and to this adding 32 we have 64.4 Fahr.

Temperature.	Expansion of Mercury.	Temp. indicated by the dilatations of the mercury supposed uniform.
0°	0	0.00
100	$\frac{1}{5550}$	100.00
200	$\frac{1}{5425}$	204.61
300	$\frac{1}{5300}$	314.15

Comparing the numbers in the first and last columns, it appears that up to 100°, the mercurial and air thermometers give the same indications; in the second interval, the excess of the former over the latter is 4.61°, and in the last interval it increases to 14.15 centigrade degrees.

The boiling point of mercury, according to these philosophers, is 680° Fahr., or, making the due correction for the expansion of glass, 662° of Fahr. scale. The experimental result of Mr. Crighton of Glasgow, was 656°.

II. *Motion of Free Caloric.*—1. *Its Radiation.* 2. *Its passage through Solids and Fluids.*

Caloric escapes from bodies in two different modes.—Part of it finds its way through space, independently of other matter, and with immeasurable velocity. In this state it has been called radiant heat, or radiant caloric.

RADIANT CALORIC exhibits several interesting properties.

1. *Its reflection.* (*a*) Those surfaces, that reflect light most perfectly, are not equally adapted to the reflection of caloric. Thus, a glass mirror, which reflects light with great effect when held before a blazing fire, scarcely returns any heat, and the mirror itself becomes warm. On the contrary, a polished plate of tin, or a silver spoon, when similarly placed, reflects, to the hand, a very sensible degree of warmth; and the metal itself remains cool. Metals, therefore, are much better reflectors of caloric than glass; and they possess this property in a higher degree, in proportion to the perfection with which they are polished.

(*b*) Caloric is reflected according to the same law that regulates the reflection of light. This is proved by an interesting experiment of M. Pictet; the means of repeating which may be attained at a moderate expense. Provide two reflectors of planished tin (*a* and *b*, fig. 45), which may be twelve inches diameter, and segments of a sphere of nine inches radius. Parabolic mirrors are still better adapted to the purpose; but they are more expensive. Each of these must be furnished, on its convex side, with the means of supporting it in a perpendicular position on a proper stand. Place the mirrors opposite to each other on a table, at a distance of from six to twelve feet. Or they may be placed in a horizontal position, as represented in the wood-cut given at page 81, an arrangement in some respects more convenient. In the focus of one, let the ball of an air thermometer, *c*, or (which is still better) one of the balls of a differential thermometer, be situated; and in that of the other, suspend a ball of iron, about four ounces in weight, and heated below ignition, or a small matrass of hot water, *d*; having previously interposed a screen before the thermometer. Immediately on withdrawing the screen, the depression of the column of liquid, in the air thermometer, evinces an increase of temperature in the instrument. In this experiment, the caloric flows first from the heated ball to the nearest reflector; from this it is transmitted, in parallel rays, to the surface of the second reflector, by which it is collected into a focus on the instrument. This is precisely the course that is followed by radiant light; for, if the flame of a taper be substituted for the iron ball, the image of the candle will appear precisely on that spot (a sheet of paper being presented for its reception) where the rays of caloric were before concentrated.

(*c*) When a glass vessel, filled with ice or snow, is substituted for the heated ball, the course of the coloured liquid in the thermometer will be precisely in the opposite direction; for its ascent will show, that the air in the ball is cooled by this arrangement. This experiment, which appears, at first view, to indicate the reflection of cold, presents, in fact, only the reflection of heat in an opposite direction; the ball of the thermometer being, in this instance, the hotter body. "And since heat emanates from bodies in quantities greater as their temperature is higher, the introduction of a cold body into the focus of one mirror, necessarily diminishes the temperature of a thermometer in the focus of the other, in the same manner as a black body placed in the focus of the one would diminish the quantity of light in the focus of the other." (Davy's Chem. Philos. p. 206.)

(*d*) In Mr. Leslie's "Enquiry into the Nature, &c. of Heat." a variety of important experiments are detailed, which show the influence of covering the reflectors with various substances, or of mechanically changing the nature of their surfaces, on their power of reflecting caloric.

2. Caloric is *refracted*, also, according to the same law that regulates the refraction of light. This interesting discovery we owe to Dr. Herschell, whose experiments and apparatus, however, cannot be understood without the assistance of a plate. For this reason, I refer to his paper in the 90th vol. of the Philosophical Transactions, or in the 7th vol. of the Philosophical Magazine.

3. The nature of the *surface* of bodies has an important influence over their power of *radiating* caloric.

To exhibit this influence experimentally, let a canister of planished block tin, forming a cube of six or eight inches, be provided, having an orifice at the middle of its upper side, from half an inch to an inch diameter, and the same in height. This orifice is intended to receive a cap having a small hole, through which a thermometer is inserted, so that its bulb may reach the centre of the canister. Let one side of the canister be covered with black paint; destroy the polish of another side, by scratching it with sand-paper; tarnish a third with quicksilver; and leave the fourth bright. Then fill the vessel with boiling water. The radiation of caloric from the blackened side is so much more abundant than from the others, as to be even sensible to the hand. Place it before a reflector (fig. 45), in lieu of the heated iron ball already described. The thermometer, in the focus of the second reflector, will indicate the highest temperature, or most copious radiation of caloric, when the blackened side is presented to the reflector; less, when the tarnished or scratched side is turned towards it; and least of all, when the polished side.

Mr. Leslie showed, also, the influence of the inclination of a surface, with respect to a given direction of calorific rays, upon the intensity of the effect produced; and first proved, experimentally, that the action of a radiant surface is proportional to the sine of the angle formed by that surface with the direction of the emitted rays.

4. The varieties in the radiating power of different surfaces are attended, as might be expected, with corresponding variations in the *rate of cooling*. If water in a tin vessel, all of whose sides are polished, cools through a given number of degrees in eighty-one minutes, it will descend through the same number in seventy-two minutes, if the surface be tarnished with quicksilver. Water, also, enclosed in a clean and polished tin ball, cools about twice more slowly than water in the same ball covered with oiled paper. Blackening the surface with paint, or even a thin coat of varnish, on the same principle, accelerates greatly the rate of cooling. These facts teach us, that vessels, in which fluids are to be long kept hot, should have their surfaces brightly polished; the best reflectors of heat being the worst radiators. The superiority of metallic tea-pots, for instance, over those of earthenware, depends on the superior polish of their surface, and the manufacturers of earthenware now increase its power of retaining heat, by a thin film of some kind of polished metal.

5. Radiant heat has the power of penetrating and passing through transparent bodies, such as plates of glass. The dull heat of a common fire is transmitted, according to Mariotte, with difficulty, and the heat from a matrass of boiling water not at all. De Laroche has shown that the loss of heat, transmitted through glass plates, is less, as the temperature of the source from which it emanates is more elevated. From a body heated to 182°, only $\frac{1}{40}$ of all the heat emitted passed through a glass screen; from one at 346°, $\frac{1}{16}$ of the whole; and from one at 960°, a much larger proportion, *viz.* $\frac{1}{4}$, appeared to pass through the screen. The same philosopher ascertained, that the heat, which has penetrated through a plate of glass, experiences, in its passage through a second plate, a loss proportionally much smaller in amount. He found, also, that a thick glass screen, though more permeable by light than a thin one of inferior quality, allowed much less radiant heat to pass, and that the difference became smaller as the temperature was raised. In all these cases, it is supposed that the screens are placed at equal distances from the radiating body; for otherwise the effect will be greatly modified by that well established law of radiant heat, according to which its intensity diminishes in proportion to the square of the distance from its source. These facts, some of which

had been called in question, have been fully confirmed by Mr. Ritchie. (Brewster's Journal, No. xiv. p. 350.)

6. Radiant caloric is *absorbed* with different facilities by different surfaces. This is only stating, in other terms, that surfaces are endowed with various powers of reflecting caloric; since the power of absorbing caloric is precisely opposite to that of reflecting it. Hence the best reflectors of heat will absorb the least. It may be proper, however, to offer some illustrations of the principle under this form.

(*a*) Expose the bulb of a sensible thermometer to the direct rays of the sun. On a hot summer's day it will probably rise, in this climate, to 108°. Cover it with Indian ink, and again expose it in a similar manner. During the evaporation of the moisture it will fall; but, as soon as the coating becomes dry, it will ascend to 118°, or upwards, of Fahrenheit, or 10° higher than when uncovered with the pigment. (Watson's Essays, v. 193.) This cannot be explained, by supposing that the black coating is gifted with the power of retaining caloric, and preventing its escape; because, from experiments already related, it appears that a similar coating accelerates the cooling of a body to which it is applied.

(*b*) Colour has considerable influence over the absorption of caloric. This is shown by the following very simple experiment of Dr. Franklin.

On a winter's day, when the ground is covered with snow, take four pieces of woollen cloth, of equal dimensions, but of different colours, *viz.*, black, blue, brown, and white, and lay them on the surface of the snow, in the immediate neighbourhood of each other. In a few hours, the black cloth will have sunk considerably below the surface; the blue almost as much; the brown evidently less; and the white will remain precisely in its former situation. Thus it appears, that the sun's rays are absorbed by the dark-coloured cloth, and excite such a durable heat, as to melt the snow underneath; but they have not the power of penetrating the white. Hence the preference generally given to dark-coloured clothes during the winter season, and to light-coloured ones in summer, appears to be founded on a sound principle.

(*c*) This experiment has been varied by Sir H. Davy, in a manner which may be repeated at any season of the year. Take six similar pieces of sheet copper, each about an inch square, and colour the one white, another yellow, a third red, the fourth green, the fifth blue, and the sixth black. On the centre of one side of each piece, put a small portion of a mixture of oil and wax, or cerate, which melts at about 76°. Then expose their coloured surfaces under precisely equal circumstances, to the direct rays of the sun. The cerate on the black plate will begin to melt perceptibly before the red; the blue next; then the green and the red; and, lastly, the yellow. The white will scarcely be affected, when the black is in complete fusion.

Caloric passes, also, but much more slowly, through solid and liquid bodies, which are then termed CONDUCTORS of caloric.

1. Solid bodies convey heat in all directions, upwards, down-

and laterally; as may be shown, by heating the middle of an d, and holding it in different directions. Professor Pictet, by concentrating the sun's rays upon the middle of a rod of kept in the axis of a glass tube, which was exhausted by the ıp, found that of two thermometers in contact with the me- : upper one indicated a quicker elevation of the mercury; ; may be accounted for by the imperfection of the vacuum, carrying power of the air unavoidably left in the tube.

me bodies conduct caloric much more quickly than others. 'o rods, of equal length and thickness, the one of glass, the f iron, with wax, at one end of each only; and then apply the uncoated ends. The wax will be melted much sooner ıe end of the iron rod, than from the glass one; which shows, ın conducts heat more quickly than glass.

the different metals possess very different powers of con- caloric. An approximation to the degree in which they this property, may be attained by the following method, ly employed by Dr. Ingenhouz. Procure several solid cy- or rods, of the same size and shape, but of different me- ıey may be six inches long, and one 4th of an inch in diame- ›at them, within about an inch of one end, with bees-wax, ing them into this substance when melted, and allowing the g to congeal. Let an iron heater be provided, in which oles have been drilled, that exactly receive the clean ends of nders. After heating it below ignition, insert the cylinders places. The conducting power may be estimated by the ›f wax coating melted from each in a given time. Accord- ıe experiments of Dr. Ingenhouz, the metals may be arrang- e following order: Silver possesses the highest conducting next gold; then copper and tin, which are nearly equal; ow these, platina, iron, steel, and lead, which are greatly to the rest.

·etz has recently given the following table. (Ann. de Ch. et :xxvi. 422.)

the Comparative Conducting Powers of the Principal Metals, and of some Earthy Bodies.

›ld (greatest conducting power)	1000,0.
lver	973,0.
atinum	981,0.
›pper	898,2.
›n	374,3.
nc	363,0.
.n	303,9.
:ad	179,6.
arble	23,6.
›rcelain	12,2.
ırth of Bricks and Furnaces	11,4.

:onducting powers of bodies have been investigated by M. , with the aid of an instrument contrived by him for the purpose, to which he has given the name of *Thermometer of Contact.* In its simplest form, it consists of a conical vessel of very thin sheet iron, filled with mercury, closed at its circular base with very thin parchment. A thermometer, whose bulb is plunged into the mercury, indicates, at each instant, the temperature of the liquid mass. By means of the flexible bottom of the cone, exact contact is made with a support placed under it, and kept at a given temperature, such as that of an apartment. When the conducting power of any substance is to be tried, a small circular disc, of the same size as the base of the cone, cut out of the substance to be tried, may be interposed between the flexible bottom and the support. The mercury is first heated to a given temperature (generally to 176° F.), and the rates of cooling, during equal intervals, are carefully noted down. If we replace the disc by another of a different material, and again observe the descent of the thermometer in equal times, the rate of cooling will be found to differ materially, however thin the plate which has been interposed; for instance, a piece of the finest paper will occasion a sensible difference. Varying the material of the interposed plates, produces very striking varieties in the ratio of cooling, and establishes a great difference of conducting power between calico, linen, flannel, and woollen cloth. The circumstance on which the efficacy of the instrument seems to depend, is the close contact effected by means of the flexible bottom; and the results are obtained with the greatest ease, either by employing thin plates, or by placing the instrument containing the heated mercury, on a mass of any substance whose conducting power it is desired to know. In equal intervals of time, for example, not exceeding five minutes, the mercury cools with very different velocities, by placing it first on iron, then on sand-stone, then on bricks, and lastly on wood. The effect, it is acknowledged by M. Fourier, is a complicated one, and requires attention to some other circumstances, especially to the specific heat of the body under trial, for which, due correction must be made. In another instrument, which he also describes under the name of *Thermoscope of Contact*, the specific heats of bodies do not share in the effects; but this instrument, being of a more complicated construction, cannot be understood without reference to the plate, (See Ann. de Chim. et de Phys. xxxvii. 291.) By the first instrument, however, a great variety of curious facts have been ascertained, which could not have been anticipated *à priori.* M. Fourier finds, for instance, that when several discs of different conducting substances are placed under the cone, the order in which they are arranged causes a material difference in the conducting powers of the aggregates.

It is chiefly owing to the different conducting powers of bodies, that they affect us, when we touch them, with different sensations of heat or cold. Thus, if we apply the hand in succession to a number of bodies (as a piece of wood, another of marble, &c.), they appear cold in very different degrees. And as this sensation is occasioned by the passage of caloric out of the hand into the body which it touches, that body will feel the coldest which carries

at the most quickly; or which, in other words, is the best
or. For the same reason, of two bodies which are heated
me degree, and both considerably above the temperature
nd, the best conductor is the hottest to the touch. Thus
ey in our pockets often feels hotter than the clothes which
it.

uid and aëriform bodies convey heat on a different princi-
i that observed in solids, viz., by an actual change in the
of their particles. That portion of the fluid, which is near-
e source of heat, is expanded, and becoming specifically
ascends, and is replaced by a colder portion from above.
. its turn, becomes heated and dilated, and gives way to a
colder portion; and thus the process goes on, as long as the
capable of imbibing heat.

ake a glass tube, eight or ten inches long, and about an
liameter. Pour into the bottom part, for about the depth
h, a little water tinged with litmus, and then fill up the
common water, pouring on the latter extremely gently,
keep the two strata quite distinct. If the upper part of the
irst heated, the coloured liquor will remain at the bottom;
e tube be afterwards heated at the bottom, the infusion will
nd will tinge the whole mass of fluid.

to a cylindrical glass jar, four inches diameter, and twelve
ee deep, let a circular piece of ice be fitted 3½ inches thick,
ather less diameter than the jar. Or water may be poured
jar to the depth of 3½ inches, and allowed to congeal by
e to a freezing atmosphere, or by surrounding it with a
of snow and salt. The ice is to be secured in its place by
s of wood, crossing each other like two diameters of a cir-
t right angles to each other. Pour, over the cake of ice,
32° temperature, to the depth of two inches; and on its
et there float a shallow circular wooden box, perforated with
From the cock of a tea-urn, filled with boiling water, and
that its spout may be above the top of the jar, suspend a
of moistened threads, the lower ends of which must rest
urface of the box. By this arrangement, when the cock is
the hot water will trickle down the threads, and will have
considerably broken. It will then spread over the surface
x, and pass through the perforated holes to the cold water
, over which it will float without mixing with it. Let the
us completely filled with hot water. The ice will remain
d for several hours at the bottom of the vessel.

ll a similar jar with hot water; and, having provided a cake
f equal size with the former one, let it be placed on the
of the water. In about three minutes, the whole will be
Both these experiments are more striking, if the water,
forming the cakes of ice, be previously coloured with lit-
r, in the latter experiment, the descending currents of cold
e thus made strikingly apparent.

hese experiments may be varied, by freezing, in the bottom
e one inch wide, a portion of water, about two inches in

depth. Then fill the tube with water of the common temperature, and hold it inclined over an Argand's lamp, so that the upper portion only of the tube may be heated. When thus disposed, the water may be made to boil violently at the surface, and yet the ice will not be melted. But if the experiment be reversed, and (the ice floating on the surface) heat be applied to the bottom of the tube, the ice will be liquefied in a few seconds.

(*e*) Substituting water of the temperature of 41° for the boiling water used in experiment (*c*), Count Rumford found, that, in a given time, a much greater quantity of ice was melted by the cooler water. This appears, on first view, rather paradoxical. The fact, however, is explained by a remarkable property of water, *viz.*, that when cooled below 40° it ceases to contract, and experiences, on the contrary, an enlargement of bulk. Water, therefore, at 40° (at the bottom of which is a mass of ice at 32°), is cooled by contact with the ice, and is expanded at the same moment. It therefore ascends, and is replaced by a heavier and warmer portion from above.

It is in consequence of the same property that the surface of a deep lake is sometimes sheeted over with ice, even when the water below is only cooled to 40°; for the superficial water is specifically lighter than the warmer water beneath it, and retains its place, till it is changed into ice. This property of water is one of the most remarkable exceptions to the law, that bodies are expanded by an increase, and contracted by a diminution, of temperature.

From these facts, Count Rumford concluded, that water is a perfect non-conductor of caloric, and that it propagates caloric in one direction only, *viz.*, upwards, in consequence of the motions which it occasions among the particles of the fluid.

The Count inferred also, that if these motions could be suspended, caloric would cease to pass through water; and, with the view of deciding this question, he made the following experiments, which admit of being easily repeated. (See his 7th Essay on Heat, 8vo. 1797.) A cylindrical tin vessel must previously be provided, two inches in diameter, and 2½ inches deep, having a moveable cover, perforated with a small aperture, for transmitting the stem of a thermometer, which is to be inserted so that its bulb may occupy the centre of the vessel.

(*f*) Fill this vessel with water of the temperature of the atmosphere; let the cover be put in its place; and let the whole apparatus, except the scale of the thermometer, be immersed in water, which is to be kept boiling over a lamp. Observe how long a time is required to raise the water from its temperature at the outset to 180°, and remove it from its situation. Note, also, how long it takes to return to its former temperature.

(*g*) Repeat the experiment, having previously dissolved in the water 200 grains of common starch. The thermometer will now require about half as long again to arrive at the same temperature. A similar retardation, and to a greater amount, is produced by the mixture of fur, eider-down, cotton-wool, and various other substances, which are not chemically soluble in water, and which can diminish its conducting power in no other way than by obstructing the motion of its particles. The same substances retard the propagation of heat through air also, by preventing the movement of its particles among each other. In general, the lighter the non-conductor, as to weight, the better does it act as an envelope to retain heat, and hence, the better is it adapted to the purpose of winter clothing. Air thus confined in small cells, appears to be a very slow conductor of caloric.

The inference, however, respecting the complete non-conducting power of water, has been set aside by the subsequent inquiries of Dr. Thomson and the late Dr. John Murray, of Edinburgh, especially by a most decisive experiment of the latter. To establish the conducting power of water, it was justly deemed indispensable, that caloric should be proved to be propagated through that fluid downwards. This, on actual trial, it appeared to be; but it was objected, that the sides of the containing vessel might be the conductor. To obviate this objection, Dr. Murray contrived to congeal water into the form of a jar, capable of holding liquids. This was separately filled with linseed oil and with mercury. At a proper distance below the surface, the bulb of a thermometer was placed; and on the surface of the liquid rested a flat iron vessel, containing boiling water. Under these circumstances, the thermometer invariably rose; and though it ascended only a very few degrees, yet it must be recollected, that the cooling power of the sides of the vessel would effectually prevent any considerable elevation of temperature. This experiment, in conjunction with others, decisively proves that water is a conductor, though a slow or imperfect one, of caloric.

SECTION III.

Caloric the Cause of Liquidity.

Almost every solid is capable of passing to the fluid state on the application of a sufficient degree of heat, which is not the same for all solids, but differs for each. In many solids the transition to the liquid form is sudden, while others pass through various stages of liquidity, before they become completely fluid. The metals and ice are examples of the first, and wax or tallow of the second kind of liquefaction. In the former, it is more easy to determine what has been called the *fusing* or *melting point*, which is constant in the same solid.

All fluids, with the exception of chloride of azote, protochloride of carbon, sulphuret of carbon, and alcohol, are capable of being solidified by reducing their temperature. When the natural form of a body is that of a liquid, and it only occasionally assumes the solid form, we call the temperature at which it is solidified, or at which, when solid, it begins to melt, the *freezing* or *congealing point;* and this is also constant in the same liquid, but different in various liquids, as will more clearly appear from the following examples.

I. *The temperature of melting snow, or of thawing ice, is uniformly the same at all times, and in all places.*—This may be ascertained by the thermometer, which will always, when immersed in liquefying ice or snow, point to 32° of Fahrenheit, whatsoever may be the height of the barometer, or the elevation, above the sea, of the place where the experiment is made. (Shuckburgh, Philosophical Transactions, lxix.)

II. *The sensible heat, or temperature of ice, of 32 Faht. is not changed by liquefaction.*—A thermometer in pounded ice stands at 32°, and at the very same point in the water which results from the liquefaction of ice; care being, of course, taken to observe the temperature of the water, at the moment when the last portion of ice has been liquefied.

III. *Yet ice, during liquefaction, must absorb much caloric.*—Expose a pound of water at 32°, and a pound of ice at 32°, in a room, the temperature of which is several degrees above the freezing point, and uniformly the same during the experiment. The water will arrive at the temperature of the room, several hours before the ice is melted; and the ice, when first melted, will exhibit, as before its liquefaction, the temperature of 32°. Yet the ice, during the whole of this time, must have been imbibing caloric, because (according to Experiment IV. § 2.) a colder body can never be in contact with a warmer one, without receiving caloric from it. The caloric, therefore, which has entered the ice, but is not to be found in it by the thermometer, is said to have *become latent.* As it is the cause of the liquefaction of the ice, it is sometimes called *caloric of fluidity*, or *constituent caloric.*

IV. *The quantity of caloric that enters into a pound of ice, and becomes latent, during liquefaction, may be learned by experiment.*—To a pound of water, at 172°, add a pound of ice at 32°. The temperature will not be the arithmetical mean (102°), but much below it, *viz.* 32°. All the excess of caloric in the hot water has therefore disappeared. From 172° take 32°; the remainder, 140°, shows the quantity of caloric that enters into a pound of ice during liquefaction; that is, as much caloric is absorbed by a pound of ice, during its conversion into water, as would raise a pound of water from 32° to 172°.

It is from the property of its uniformly absorbing the same quantity of caloric for conversion into water, that ice was applied, by Lavoisier and Laplace, to the admeasurement of the heat evolved in certain operations. Let us suppose the body (from which the caloric, evolved either by simple cooling or combustion, is to be measured,) to be inclosed in a hollow sphere of ice, with an opening at the bottom. When thus placed, the heat which is given out will be all employed in melting the ice; and will produce liquefaction in direct proportion to the quantity of heat evolved. Hence the quantity of ice, which is converted into water, will be a measure of the caloric that is separated from the body submitted to experiment. In this way, Lavoisier ascertained that equal weights of different combustible bodies melt, by burning, very different weights of ice. The apparatus which he employed for this purpose he has called the *calorimeter.* Its construction can scarcely be understood without the plate, which accompanies the description in his "Elements of Chemistry;" and I consider it unnecessary to copy it into this work, because the instrument is liable to several causes of fallacy, which render it quite inadequate to the accurate measurement of heat.

V. *The heat rendered latent by the fusion of various bodies is not a constant quantity, but various for each individual body.* This is shown by the following results of the experiments of the two Drs. Irvine:

	Caloric of fluidity.	Do. reduced to the sp. heat of water.
Sulphur	143.68° Fahr.	27.14
Spermaceti	145	
Lead	162	5.6
Bees-wax	175	
Zinc	493	48.3
Tin	500	33.
Bismuth	550	23.25

All the bodies enumerated in the table, require, it may be observed, more caloric to bring them into a fluid state than is necessary to convert ice into water, for which 140° are sufficient.

VI. *Other examples of the absorption of caloric, during the liquefaction of bodies,* are furnished by the mixture of snow and nitric acid, or of snow and common salt, both of which, in common language, produce intense cold.

1. Dilute a portion of nitric acid with an equal weight of water; and, when the mixture has cooled, add to it a quantity of light fresh-fallen snow. On immersing the thermometer in the mixture, a very considerable reduction of temperature will be observed. This is owing to the absorption and intimate fixation of the free caloric of the mixture by the liquefying snow.

2. Mix quickly together equal weights of fresh-fallen snow at 32°, and of common salt, cooled, by exposure to a freezing atmosphere, down to 32°. The two solid bodies, on admixture, will rapidly liquefy; and the thermometer will sink 32°, or to 0; or, according to Sir C. Blagden, to 4° lower. (Philosophical Transactions, lxxviii. 281.) To understand this experiment, it must be recollected that the snow and salt, though at the freezing temperature of water, have each a considerable portion of uncombined caloric. Now salt has a strong affinity for water; but the union cannot take place while the water continues solid. In order, therefore, to act on the salt, the snow absorbs all the free caloric required for its liquefaction; and, during this change, the free caloric, both of the snow and of the salt, amounting to 32°, becomes latent, and is concealed in the solution. This solution remains in a liquid state at 0, or 4° below 0 of Fahrenheit; but, if a greater degree of cold be applied to it, the salt separates in a concrete form.

3. Most neutral salts, also, during solution in water, absorb much caloric; and the cold, thus generated, is so intense as to freeze water, and even to congeal mercury. The former experiment, however, (*viz.* the congelation of water,) may easily be repeated on a summer's day. Add to 32 drachms of water 11 drachms of muriate of ammonia, 10 of nitrate of potassa, and 16 of sulphate of soda, all finally powdered. The salts may be dissolved separately, in the order set down. A thermometer, put into the solution, will show, that the cold produced is at or below freezing; and a little water, in a thin glass tube, being immersed in the solution, will be frozen in a few minutes. Various other freezing mixtures are described in Mr. Walker's papers in the Philosophical Transactions for 1787, 88, 89, 95, and 1801. Of these the table, given in the Appendix, for which I am indebted to the obliging communication of the author, contains an arranged abstract.

4. Crystallized muriate of lime, when mixed with snow, produces a most intense degree of cold. This property was discovered, some years ago, by M. Lovitz, of St. Petersburg, and has been since applied, in this country, to the congelation of mercury on a very extensive scale. The proportions which answer best are about equal weights of the salt, finely powdered, and of fresh-fallen and light snow. On mixing these together, and immersing a thermometer in the mixture, the mercury sinks with great rapidity. For measuring exactly the cold produced, a spirit thermometer, graduated to 50° below 0 of Fahrenheit, or still lower, should be employed. A few pounds of the salt are sufficient to congeal a large mass of mercury. By means of 13 pounds of the muriate, and an equal weight of snow, Messrs. Pepys and Allen froze 56 pounds of quicksilver into a solid mass. The mixture of the whole quantity of salt and snow, however, was not made at once, but part was expended in cooling the materials themselves.

On a small scale it may be sufficient to employ two or three pounds of the salt. Let a few ounces of mercury, in a very thin glass retort, be immersed, first in a mixture of one pound of each; and, when this has ceased to act, let another similar mixture be prepared. The second will never fail to congeal the quicksilver. The salt thus expended may be again evaporated, and crystallized for future experiments.

In plate iv. fig. 42, a very simple and cheap apparatus is represented, which I have generally employed to freeze mercury. The dimensions will be given in the description of the plates. (See the Appendix.)

The reader, who wishes for further particulars respecting experiments on mercurial congelation, is referred to the Philosophical Magazine, iii. 76.

VII. *On the contrary, liquids, in becoming solid, evolve or give out caloric, or, in common language, produce heat.*

1. Water, if covered with a thin stratum of oil, and kept perfectly free from agitation, may be cooled down more than twenty degrees below 32°; but, on shaking it, or dropping into it a small

fragment of ice, it immediately congeals, and the temperature rises to 32°. (Blagden, Phil. Trans. 1788.)

2. Expose to the atmosphere, when at a temperature below freezing, (for example, at 25° of Fahrenheit,) two equal quantities of water, in one only of which about a fourth of its weight of common salt has been dissolved. The saline solution will be gradually cooled, without freezing, to 4°. The pure water will progressively descend to 32°, and will there remain stationary a considerable time before it congeals. Yet, while thus stationary, it cannot be doubted that the pure water is yielding caloric to the atmosphere, equally with the saline solution; for it is impossible that a warmer body can be surrounded by a cooler one without imparting caloric to the latter. The reason of this equable temperature is well explained by Dr. Crawford. (*On Heat*, p. 80.) Water, he observes, during freezing, is acted upon by two opposite powers: it is deprived of caloric by exposure to a medium whose temperature is below 32°; and it is supplied with caloric by the evolution of that principle from itself, *viz.* of that portion which constituted its fluidity. As these powers are exactly equal, the temperature of the water must remain unchanged, till the caloric of fluidity is all evolved.

3. The evolution of caloric, during the congelation of water, is well illustrated by the following experiment of Dr. Crawford: —Into a round tin vessel put a pound of powdered ice; surround this by a mixture of snow and salt in a larger vessel; and stir the ice in the inner one till its temperature is reduced to + 4° of Fahrenheit. To the ice thus cooled, add a pound of water at 32°. One 5th of this will be frozen; and the temperature of the ice will rise from 4° to 32°. In this instance the caloric, evolved by the congelation of one 5th of a pound of water, raises the temperature of a pound of ice 28°.

4. If we dissolve sulphate of soda in water, in the proportion of one part to five, and surround the solution by a freezing mixture, it cools gradually down to 31°. The salt at this point begins to be deposited, and stops the cooling entirely. This evolution of caloric, during the separation of a salt, is exactly the reverse of what happens during its solution. (Blagden, Philosophical Transactions, lxxviii. 290.)

5. To a saturated solution of sulphate of potassa in water, or of any salt that is insoluble in alcohol, add an equal measure of alcohol. The alcohol, attracting the water more strongly than the salt, precipitates the salt, and considerable heat is produced.

SECTION IV.

Caloric the Cause of Vapour.

I. *Every liquid, when of the same degree of chemical purity, and under equal circumstances of atmospheric pressure, has one peculiar point of temperature, at which it invariably boils.*—Thus pure water always boils at 212°, alcohol of sp. gr. 0.813, at 173°, and ether at 96°, Fahr.; and, when once brought to the boiling point, no liquid can be made hotter, however long the application of heat be continued. The boiling point of water may be readily ascertained, by immersing a thermometer in water boiling, in a metallic vessel, over the fire. As there is some danger in applying heat directly to a vessel containing either ether or alcohol, the ebullition of these fluids may best be shown by immersing the vessel containing them in water, the temperature of which may be gradually raised. The appearance of boiling is owing to the formation of vapour at the bottom of the vessel, and its escape through the heated fluid above it. That the steam, which escapes, is actually formed at the bottom, and not at the top of the water, may be seen by boiling some water in a Florence flask, or other transparent vessel, over an Argand's lamp. The bubbles of vapour will evidently ascend from the bottom of the vessel.

A few exceptions to the fixity of the boiling point of liquids, arising chiefly from the material of which the containing vessel is made, have been stated by Gay Lussac.* Under a mean pressure, the boiling point of water in a metallic vessel is generally 212°; in a glass vessel it rises as high as 216°, but may be stated on an average at 214°. Even in the same glass vessel the boiling point is found to vary considerably. This appears to be owing to some irregularity in the formation of steam, which may be observed to burst forth occasionally in large bubbles, the escape of which is immediately followed by a fall of the thermometer. If iron or copper filings, platinum wire, or even pounded glass, be thrown into the glass vessel of water thus heated, steam is instantly formed in great abundance, and the boiling point is immediately lowered two or three degrees. By putting coils of wire into liquids, heated in glass vessels with a view to their distillation, they are made to boil quietly, and some degrees lower than they would otherwise do. It is, of course, necessary to use a metal which is not acted upon by the particular fluid under distillation; platinum, for instance, when we operate on sulphuric acid. A similar change of the boiling point, by the presence of extraneous substances, has been found by Dr. Bostock to take place in ether and alcohol. Ether, heated in a glass vessel, had its boiling point lowered nearly 50° by introducing a few chips from a cedar pencil, and alcohol of s. g. .849 had its boiling point reduced by the same means, between 30° and 40°. The boiling point of water, heated in a glass vessel, was brought down 4° or 5° by the same method. (Ann. of Phil. N. S. ix. 196.)

II. *Steam has exactly the same temperature as boiling water.*—Let a tin vessel be provided, having two holes in its cover, one of which is just large enough to admit the stem of a thermometer. Fill it partly with water, and let the bulb of the thermometer be an inch or two above the surface of the water, leaving the other aperture open for the escape of vapour. When the water boils, the thermometer, surrounded by steam, will rise to 212°, which is precisely the temperature of the water beneath; yet water, placed on a fire, continues to receive heat, very abundantly, even when boiling hot; and as this heat is not appreciable by the thermometer, it must exist in the steam in a latent state. With saline solutions, the temperature of the steam arising from them, is the same as that of the boiling solution itself. (Ann. Phil. N. S. v. 75.) The boiling points of a considerable number of saturated solutions are exhibited in the form of a Table in the Quarterly Journal of Science, xviii. 89.

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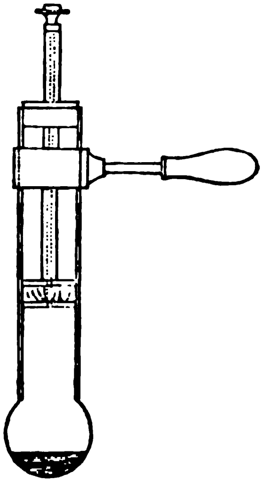
* Ann. de Chim. et de Phys. vii. 307, or Journ. of Science, v. 361.

III. *Perfectly formed steam is completely invisible.*—We may satisfy ourselves of this by boiling strongly a small quantity of water in a flask; for perfect transparency will exist in the upper part of the vessel. It is only when it begins to be condensed, that steam becomes visible. We have a proof also of the same fact in the thick fogs which are produced by a sudden transition from warm to cold weather; the vapour, which was imperceptible at the high temperature, being condensed and rendered visible by the lower.

The perfect transparency of steam, and also two other important properties on which depends its use as a moving power, viz. its elasticity and its condensibility by a reduced temperature, are beautifully shown by a little apparatus contrived by Dr. Wollaston, of which a sketch is annexed. It consists of a glass tube about 6 inches long and $\frac{1}{2}$ inch bore, as cylindrical as possible, and blown out a little at the lower end. It has a wooden handle, to which is attached a brass clip embracing the tube; and within is a piston, which, as well as its rod, is perforated, as shown by the dotted lines. This canal may be occasionally opened or closed by a screw at the top; and the piston rod is kept in the axis of the cylinder by being passed through a hole in a piece of cork fixed at the top of the tube. When the instrument is used, a little water is put into the bottom; the piston is then introduced with its aperture left open; and the water is heated over a spirit lamp. The common air is thus expelled from the tube, and when this may be supposed to be effected, the aperture in the rod is closed by the screw. On applying heat, steam is produced, which drives the piston upwards. On immersing the bulb in water, or allowing it to cool spontaneously, a vacuum is produced in the tube, and the piston is forced downwards by the weight of the atmosphere. These appearances may be alternately produced, by repeatedly heating and cooling the water in the ball of the instrument. In the original steam engine, the vapour was condensed in the cylinder, as it is in the glass tube; but in the engine as improved by Mr. Watt, the steam is pumped into a se-



parate vessel, and there condensed; by which the loss of heat, occasioned by cooling the cylinder every time, is avoided.

IV. *The boiling point of the same fluid varies, under different degrees of atmospheric pressure.*—Thus water, which has been removed from the fire, and has ceased to boil, has its ebullition renewed when it is placed under a receiver, the air of which is quickly exhausted by an air pump. Alcohol and ether, confined under an exhausted receiver, boil violently at the temperature of the atmosphere. In general, liquids boil *in vacuo*, with about 124° less of heat, than are required under a mean pressure of the atmosphere; (Black's Lectures, i. 151.) water, therefore, in a vacuum, must boil at 88°, and alcohol at 49° Fahr. Even the ordinary variations in the weight of the air, as measured by the barometer, are sufficient to make a difference in the boiling point of water of several degrees between the two extremes,* as shown in the following table.

Height of Barometer.	Boiling point of water.	Height of Barometer.	Boiling point of water.
26	204.91°	29	210.19°
26.5	205.79	29.5	211.07
27	206.67	30	212
27.5	207.55	30.5	212.88
28	208.43	31	213.76
28.5	209.31		

On ascending considerable heights, as to the tops of mountains, the boiling point of water gradually falls on the scale of the thermometer. Thus on the summit of Mont Blanc, water was found by Saussure to boil at 187° Fahrenheit. On this fact is founded the use of the thermometer in the measurement of heights, which, though originally suggested by Fahrenheit, has only within the few last years been made conveniently practicable, by the invention of a thermometer, adapted to the purpose, by the Rev. Mr. Wollaston. (Phil. Trans., 1817.) Without entering into minute details, it would not be possible to give a clear idea of the instrument. It may be sufficient to state, that each degree about the boiling point is made to occupy a space, that admits of being distinctly divided into 1000 parts. And as each degree of Fahrenheit is equivalent to 0.589 of an inch of the barometer, which indicates an elevation of 530 feet, it follows that one thousandth part of a degree will be equivalent to a difference in height of about six inches. In fact, the height of a common table produces a manifest difference in the boiling point of water, as ascertained by this very sensible instrument.

The influence of a diminished pressure, in causing ebullition to take place at a lower temperature, may also be illustrated by the following simple experiment:—Place over a lamp a Florence flask about three-fourths filled with water; let it boil briskly during [illegible] few minutes; and, immediately on removing it from the lamp, cork

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* Sir G. Shuckburgh, in Philosophical Transactions, lxxix. 375, and Gen. Ro[illegible] in ditto, lxvii. 687.

htly, and suddenly invert it. The water will now cease to boil;
on cooling the convex part of the flask by a stream of cold wa-
he boiling will be renewed. Applying boiling water from the
t of a tea-kettle to the same part of the flask, the water will
i cease to boil. This renewal of the ebullition, by the applica-
of cold (an apparent paradox), is owing to the formation of an
rfect vacuum over the hot water, by the condensation of steam;
he suspension of boiling, on re-applying the heat, to the re-
d pressure on the surface of the hot water, occasioned by the
ation of fresh steam.

om the facts which have been stated, it may be inferred, that
articles of caloric are mutually repulsive, and that they com-
icate this repulsive tendency to other bodies in which caloric
ntained. This repulsive power tends to change solids into
s, and liquids into aëriform bodies, and is chiefly counteracted
e pressure of the atmosphere. Were this counteracting cause
ved, many bodies, which at present have a liquid form, would
to be such, and would exist permanently in a gaseous state.
sely the same effect, therefore, results from the prevalence of
r of these forces. Add to certain liquids a quantity of caloric,
her words, place them in a high temperature, and they imme-
ly assume an aëriform state. Again, their temperature re-
ing the same, diminish the weight of the atmosphere; and the
ric, which they naturally contain, exerts its repulsive tendency
equal effect, and they are in like manner converted into gases.
e facts are best shown by the following experiments on ether:

Ether, at the temperature of 96°, exists in the state of a gas.
may be shown by filling a jar with water a few degrees above
emperature, and inverting it in a vessel of the same. Then
duce a little ether, by means of a small glass tube, closed at
nd. The ether will rise to the top of the jar, and, in its ascent,
e changed into gas, filling the whole jar with a transparent,
ible, elastic fluid. On permitting the water to cool, the ethe-
gas is condensed, and the inverted jar again becomes filled
water.

Ether is changed into gas by diminishing the weight of the
sphere. Into a glass tube, about six inches long, and half an
in diameter, put a tea-spoonful of ether, and fill up the tube
water; then, pressing the thumb on the open end of the tube,
it, inverted, in a jar of water. Let the whole be set under
eceiver of an air-pump, and the air exhausted. The ether
be changed into gas, which will expel the water entirely from
tube. On re-admitting the air into the receiver, the gas is
n condensed into a liquid.

is evidently unnecessary that a liquid should boil *in vacuo*,
der to be converted into vapour; for all liquids have, in fact, at
y temperature, a tendency to assume the state of gas, and
ral which exhibit, at the common temperature of the atmo-
re, no appearance of ebullition, are nevertheless convertible
vapour, at that temperature, under an exhausted receiver.
quantity of vapour, produced *in vacuo*, varies with the space,

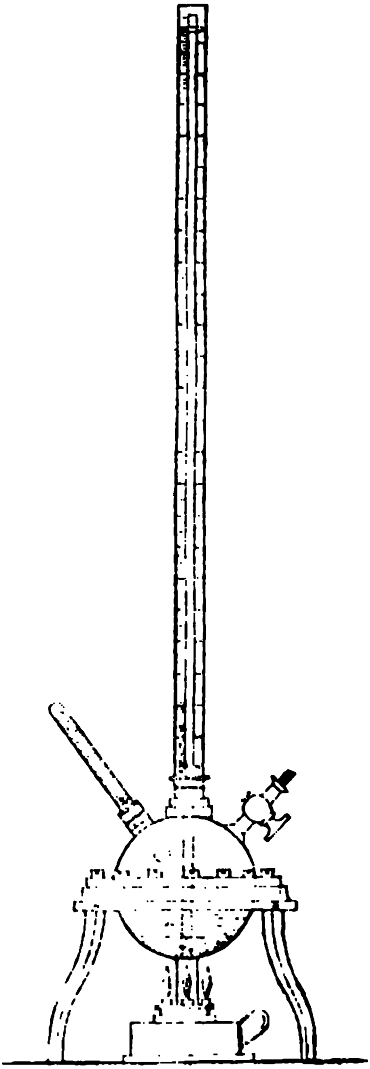
the temperature, and the nature of the liquid. 1st, It is proportional to the space, for a double space gives occasion to the formation of a double quantity of vapour; and, if a given volume of vapour be mechanically compressed into half its bulk, one half will be re-converted into water. 2dly, It increases with the temperature, but in a greater proportion. 3dly, It is different for different liquids; and it may be observed that liquids, which enter most easily into ebullition, are generally, though with some exceptions, those which, at a given temperature, afford the densest vapour. Thus the vapour of ether is more dense than that of water. The caloric required to produce this sort of evaporation, which may be called *spontaneous*, in order to distinguish it from that prodnced by obvious sources of heat, is supplied in the first instance by the liquid itself, the temperature of which is at first observed to fall, and is afterwards restored by the influx of heat from surrounding bodies.

Spontaneous evaporation goes on, also, from the surface of liquids exposed to the atmosphere, and a quantity of vapour is produced, which, from the same liquid, is determined by the pressure and the temperature. If to a given volume of dry atmospheric air confined over mercury, we admit a small quantity of water, the volume of the air is increased by the admixture of aqueous vapour. Substituting, at the same temperature and pressure, any other gas for atmospheric air, an expansion is produced to precisely the same amount: and it is remarkable that the quantity and force of vapour, in a given volume of air or of gas of extreme moisture, is precisely the same as in a Toricellian vacuum of like volume. (Dalton's New System, p. 153.) These facts show, as will afterwards more fully appear, that spontaneous evaporation is entirely independent of any affinity of air for water, and is to be explained entirely by the general laws regulating the production and force of vapour.

V. *By considerably increasing the pressure, water may be heated to above 400° Fahrenheit, without being changed into vapour.*—This experiment requires, for its performance, *Papin's digester*, which is merely a strong vessel of iron or any other tenacious metal, the lid of which is firmly screwed down, after introducing the fluid which is to be heated. To prevent the vessel from being burst, its lid is provided with a safety valve, which may be loaded with any weight that may be thought necessary and prudent. That the boiling point of water, and the temperature of steam, are raised by an increased pressure, may be equally well shown by means of the small boiler, represented plate v. fig. 46, which will be found extremely useful in experiments on this subject. Its precise size, and directions for its construction, will be given in the description of the plates.

On the cock *c* may be screwed, occasionally, a valve, loaded in the proportion of 14 pounds to the square inch; or a gauge adapted to show the density of the steam, by the diminution of volume in a confined portion of air, which will occupy a bulk inversely proportionate to the compressing force (fig. 46, *f*.) The boiler being rather more than half filled with water, and the perforated cap *d* being screwed into its place, the ball of the thermometer will be an inch or more above the surface of the water, and will indicate its temperature, as well as that of the steam, both being, necessarily, in all cases, precisely the same. Allowing the steam to escape through the cock c, before affixing the valve, the temperature of the steam, under a mean atmospheric pressure, will be 212°. When an additional atmosphere is added by the weighted valve, it will rise to 250°; by a valve twice as heavy as the first, or loaded in the proportion of 42 pounds to the square inch (=three atmospheres), the temperature of the steam will be raised to more than 270°. This is as far as it is safe to carry the experiment.

An apparatus adapted to the same purposes has been contrived, also, by Dr. Marcet, and may be procured from the makers of philosophical instruments in London. It consists of two hemispheres (see the figure), generally of brass, which are fixed together by flanches and screws. At the upper part are three openings, into one of which a cock may be screwed; into the other a thermometer graduated to 250°, or upwards; and into the central one is fixed a long glass tube open at both ends, and reaching to within about one-eighth of an inch of the bottom of the boiler. When the apparatus is used, mercury sufficient to fill the tube is first put into the vessel, and over this a quantity of water sufficient to occupy about half its capacity is poured, and the cock being shut, the heat of a spirit lamp with three or four wicks is applied. With this boiler, precisely the same experiments may be made as with that which I have already described, the only difference being in its form, and in the gauge for measuring the force of the steam which is generated; for this, by its pressure, drives the mercury up the tube, and by the height of the column exhibits in a more striking manner the correspondence between the elasticity of the steam and its temperature.



The elasticity of the vapour of water from 32° to 212° Fahr. had been experimentally determined by Mr. Dalton, who, from his results, had calculated its force at temperatures above the ordinary boiling point. It was still, however, desirable to ascertain, by actual experiment, the elastic force of vapour above 212°, and this has been attempted by Professor Robinson, Mr. Southern, and Dr. Ure. Mr. Southern's experiments were made many years ago, but were first published in Dr. Brewster's edition of Prof. Robinson's Works. The following table expresses the elasticity of aqueous vapour according to his experiments, under one, two, four, and eight atmospheres.

Atmospheres.	Pressure in Inches of Mercury.	Temperatures Fahr.
1	29.8	212.°
1½	44.7	234.
2	59.6	250.3
2½	74.5	264.2
3	89.4	275.
3½	104.3	285.3
4	119.2	293.4
4½	134.1	302.
5	149.	309.2
5½	163.9	316.4
6	178.8	322.7
6½	193.7	328.5
7	208.6	334.4
7½	223.5	339.8
8	238.4	343.6

Dr. Ure's experiments were published in the Philosophical Transactions for 1818, and their general results are contained in a table, which will be found in the Appendix. Between 32° and 212°, an almost exact coincidence may be observed between the experiments of Dalton and of Ure; but this ceases above the boiling point of water; for there Mr. Dalton's numbers were calculated on the presumption that the same law of progression obtains in the higher as in the lower ranges, which does not appear to be correctly the fact.

Dr. Ure has examined, also, the elastic forces of the vapours of alcohol, ether, oil of turpentine, and naphtha, and has exhibited the results in the form of a table. To the experiments on ether, it has, however, been objected by Mr. Dalton, that they were made on that fluid in an impure state, as is evident from its boiling point, which Dr. Ure states at 104° or 105°; whereas the point, at which pure ether boils under the pressure of the atmosphere, is 96° Fahr. Mr. Dalton has, therefore, from his own experiments, constructed a fresh table, which will also be found in the Appendix.

VI. *The density of steam is nearly, if not accurately, proportional to its elasticity;* at least this may be affirmed of it within the limits of Mr. Southern's experiments, which extended to steam formed under a pressure of 120 inches of mercury, or of four atmospheres.

Thus steam of elasticity = 40 inches of mercury required 1.430 cubic inches of water to form each cubic foot of steam; vapour of 80 inches required 2.940 cubic inches of water; and vapour = 120 inches force required for each cubic foot 4.279 cubic inches of water. The elasticities, therefore, and the quantities of water, in these experiments, have the same common multiple: in other words, steam of double, triple, &c. elastic force contains, in an equal volume, twice, thrice, &c. the weight of water.

VII. *The force of vapour from different liquids varies at the same temperature.* This is best shown by the following elegant contrivance of Mr. Dalton. Take a barometer tube, perfectly dry, and fill it with mercury just boiled, marking the place where it is stationary: then, having graduated the tube into inches and tenths, pour a little ether, water, or any other liquid the subject of experiment, into it, so as to moisten the whole inside. After this, again pour in mercury, and invert the tube, carefully excluding air. The barometer, by standing some time, will exhibit a portion of the liquid employed, of $\frac{1}{8}$th or $\frac{1}{10}$th of an inch, upon the top of the mercurial column, because, being lighter, it ascends by the side of the tube, which may now be inclined, and the mercury will rise to the top, manifesting a perfect vacuum from air. When the ordinary barometer is at the mean height (29.8) and the thermometer at 50°, the force of vapour in the ether barometer will depress the mercury nearly 10 inches; of sulphuret of carbon about 8$\frac{1}{2}$ inches; that of alcohol about an inch; and that of water only about 0.4 inch, showing that the force of vapour from each liquid in a vacuum is proportionate to its evaporability.

Exposing vapour thus confined to higher and lower temperatures than that of the atmosphere, Mr. Dalton determined *that the variation of the force of vapour from all liquids is the same for the same variation of temperature, reckoning from vapour of any given force.* Thus, assuming a force equal to 30 inches of mercury as the standard, it being the force of any liquid boiling in the open air, we find aqueous vapour loses half its force by a diminution of 30° of temperature. So also does the vapour of any other liquid lose half its force by diminishing its temperature 30° below that at which it boils, and the like for any other increment or decrement of heat. This position Mr. Dalton established by a train of satisfactory experiments.

VIII. *The latent heat of the vapours of fluids, though constant for vapour of the same kind, and of a given elasticity, differs in different vapours.*

The latent heat of the vapours of different liquids has been investigated by Dr. Ure and by M. Despretz. The method employed by both was to distil off a known quantity of each liquid, and to observe the temperature gained by the water employed to condense its vapour. From the results, Dr. Ure has constructed the following Table. (Dict. of Chemistry, p. 289.)

General Table of Latent Heat of Vapours.

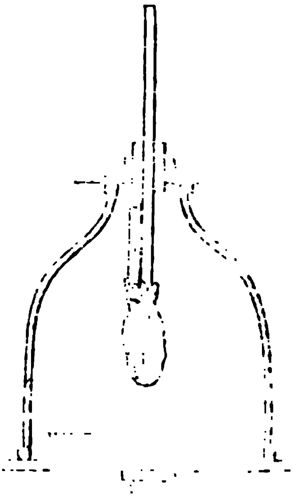
Vapour of	water at its boiling point	1000.
	alcohol (sp. gr. 0.825)	457.
	sulph. ether (boiling point 104°)	312.9
	petroleum	183.2
	oil of turpentine (do. about 310°)	183.8
	nitric acid (sp. gr. 1.494, boiled at 165°)	550.
	liquid ammonia (sp. gr. 0.978)	865.9
	vinegar (sp. gr. 1.007)	905.

The following numbers result from the experiments of M. Despretz. (Ann. de Chim. et de Phys. xxiv. 329.)

Vapour of	water	955°.8
	alcohol (sp. gr. .793)	373°.86
	ether (sp. gr. .715)	163°.44
	oil of turp. (sp. gr. .872)	138°.24

IX. *The absorption of caloric, during evaporation, shown by a very simple experiment.* Moisten a thermometer with alcohol, or with ether, and expose it to the air, repeating these operations alternately. The mercury of the thermometer will sink at each exposure, because the volatile liquor, during the evaporation, robs it of its heat. In this way (especially with the aid of an apparatus described by Mr. Cavallo, in the Philosophical Transactions, 1781, p. 509), water may be frozen in a thin and small glass ball, by means of ether. The same effect may be obtained, also, by immersing a tube, containing water at the bottom, in a glass partly filled with ether, which is to be placed under the receiver of an air-pump; or the ether may be allowed to float on the surface of the water. During the exhaustion of the vessel, the ether will evaporate rapidly; and, robbing the water of heat, will completely freeze it; thus exhibiting the singular spectacle of two fluids in cortact with each other, one of which is in the act of boiling, and the other of freezing, at the same moment.

By a little modification of the experiment, mercury itself, which requires for congelation a temperature of almost 40° below 0 of Fahrenheit, may be frozen, as was first shown by Dr. Marcet. (34 Nich. Journ. 119.) A conical receiver, open at the top, is placed on the plate of an air-pump, and a small tube, with a cylindrical bulb at its lower end, containing mercury, is suspended within the receiver, through the aperture, by means of a brass plate, perforated in its centre, and fitting the receiver air-tight, when laid upon its open neck. The tube passes through this plate, to which it is fit-



ted by a leather adjustment, or simply by a cork secured with sealing-wax. The bulb is then wrapped up in a little cotton wool, or, what is better, in a small bag of fine fleecy hosiery, in which a small spirit thermometer, graduated below 40° Fahr., may also be included; and, after being dipped into sulphuret of carbon or ether, the apparatus is quickly placed under the receiver, which is exhausted as rapidly as possible*. In two or three minutes the temperature sinks to about 45° below 0, at which moment the quicksilver in the stem suddenly descends with great rapidity. If it be desired to exhibit the mercury in a solid state, common tubes may be used, which have originally been about an inch diameter, but have been flattened by pressure, when softened by the blow-pipe. The experiment succeeds when the temperature of the room is as high as + 40° Fahrenheit.

X. *The fixation of caloric in water, by its conversion into steam, may be shown by the following experiments:*—1. Let a pound of water at 212°, and eight pounds of iron filings at 300°, be suddenly mixed together. A large quantity of vapour will be instantly generated; and the temperature of the mixture will be only 212°; but that of the vapour produced is also not more than 212°; and the steam must therefore contain, in a latent or combined form, all the caloric which raised the temperature of eight pounds of iron filings from 212° to 300°.

2. When a quantity of water is heated several degrees above the boiling point in a close vessel, and a cock is then suddenly opened, the steam rushes out with prodigious noise and violence, and the heat of the water is reduced in three or four seconds to the boiling temperature. The water, however, constituting the steam which has escaped, amounts to only a very trifling quantity, and yet it has been sufficient to carry off the whole excess of heat from the water in the digester.

3. The quantity of caloric, which becomes latent during the formation of steam, may be approximated, by repeating the following experiment of Dr. Black. He placed two cylindrical flat-bottomed vessels of tin, five inches in diameter, and containing a small quantity of water at 50°, on a red hot iron plate, of the kind used in kitchens. In four minutes the water began to boil, and in twenty minutes the whole was boiled away. In four minutes, therefore, the water received 162° of temperature, or 40½° in each minute. If we suppose, therefore, that the heat continues to enter the water at the same rate, during the whole ebullition, we must conclude that 40½° × 20 = 810° have entered the water, and are contained in the vapour.

It has been found by experiment that 75 pounds of Newcastle coal, or 100 pounds of coal of medium quality, applied in the best manner, are required for the evaporization of 12 cubic feet, or about 89¾ wine gallons of water. In practice, a pound of coal, on the average, may be considered as equivalent to convert a gallon (= 8 pounds avoirdupois) of water into vapour. Wood charcoal, by combustion, is capable of melting 94 times its weight of ice, and of evaporating 13 times its weight of water, previously at 32° Fahrenheit. Peat of the best quality, when properly applied, evaporates 10 times its weight of water, but, as commonly used, only 4 or 5 times. Even with the assistance of heated air, only six times its weight can be evaporated, though Curaudau pretends to have evaporated 25 times its weight. (79 Ann. Ch. 86.) From evidence given before the House of Commons on the Gas Light Bill, 17½ pounds of good London coke appear to be capable of raising from 66 to 70 pounds of water into vapour, or about 4 times their weight.*

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* In exhausting a vessel containing either of these fluids, the valves of the air pump must be metallic.

XI. *Water, by conversion into steam, has its bulk prodigiously enlarged,* viz., *according to Mr. Watt's experiments, about* 1800 *times, or, according to Gay Lussac, only* 1698 *times.*—A cubic inch of water (or 252 grains) occupies, therefore, when converted into steam, of temperature 212°, and force equal to 30 inches of mercury, the space of nearly a cubic foot. The specific gravity of aqueous vapour under the ordinary pressure of the air, is to that of perfectly dry air, taking Gay Lussac's data, as 10 to 16, or 0.62349 to 1. The specific gravity which it ought to have from theory is 0.620, for this should result from condensing, into two volumes, two volumes of hydrogen gas, sp. gr. 0.0688, and one volume of oxygen gas, sp. gr. 1.1025. The experimental result of Gay Lussac was obtained by comparing air and steam at the common temperature of 212° Fahr. (Ann. de Chim. et de Phys. ii. 135.) But as all gases and vapours are expanded or contracted to the same amount by equal variations of temperature, it must be obvious that the same relation will continue between air and aqueous vapour at all other degrees of heat, provided both are subjected to a common temperature and pressure. Steam, therefore, when once formed, derives no greater increase of elastic force, by raising its temperature, than air; and no danger can arise from heating a confined portion of steam, provided the vessel contains no water, from which fresh steam might be generated. In that case, its volume (and if not suffered to expand, its elasticity) is increased about one-tenth of the original amount, by every addition of about 50° Fahr.

XII. *On the contrary, vapours, during their conversion into a liquid form, evolve, or give out, much caloric.*—The heat given out by the condensation of steam, is rendered apparent by the following experiment. Mix 100 gallons of water at 50° with 1 gallon of water at 212°; the temperature of the water will be raised about 1¼°. Condense, by a common still-tub, 1 gallon of water, from the state of steam, by 100 gallons of water, at the temperature of 50°. The water will be raised 11°. Hence, 1 gallon of water, condensed from steam, raises the temperature of 100 gallons of cold water 9½° more than 1 gallon of boiling water; and, by an easy calculation, it appears that the caloric imparted to 100 gallons of cold water by 8 pounds of steam, if it could be condensed in 1 gallon of water, would raise it to 950°;* and 1 gallon of water converted into steam of ordinary density, contains as much heat as would bring 5¼ gallons of ice-cold water to the boiling point. The quantity of ice, which is melted by steam of mean density, is invariably 7½ times the weight of the steam.

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* See also Count Rumford's Researches on the Heat developed in Combustion. Phil. Mag. xli. xlii. and xliii.

For exhibiting the latent heat of steam, by means of a small apparatus, which may be placed on a table, and with the assistance only of a lamp, the boiler already described (fig. 46) will be found extremely well adapted. The right angled pipe *c* must be screwed, however, into its place, and must be made to terminate at the bottom of a jar, containing a known quantity of water of a given temperature. This conducting pipe and the jar should be wrapped round with a few folds of flannel. The apparatus being thus disposed, let the water in the boiler be heated by an Argand's lamp, with double concentric wicks, till steam issues in considerable quantity through the cock *c*, which is then to be closed. The steam will now pass through the right angled pipe into the water contained in the jar, which will condense the steam, and will have its temperature very considerably raised. Ascertain the augmentation of temperature and weight; and the result will show, how much a given weight of water has had its temperature raised by a certain weight of condensed steam. To another quantity of water, equal in weight and temperature to that contained in the jar at the outset of the experiment, add a quantity of water at 212°, equal in weight to the condensed steam; it will be found, on comparison of the two resulting temperatures, that a given weight of steam has produced, by its condensation, a much greater elevation of temperature, than the same quantity of boiling water. This will be better understood by the following example, taken from actual experiment.

Into eight ounces of water, at 50° Fahrenheit, contained in the glass jar, *f*, fig. 46, steam was passed from the boiler, till the temperature of the water in the jar rose to 173°. On weighing the water, it was found to have gained 8¼ drachms; that is, precisely 8¼ drachms of steam had been condensed, and had imparted its heat to the water.—To facilitate the explanation of this experiment, it is necessary to premise the following remarks.

To measure the whole quantities of caloric contained in different bodies, is a problem in chemistry which has not yet been solved. But the quantities of caloric added to, or subtracted from, different bodies (setting out from a given temperature) may, in many cases, be measured and compared with considerable accuracy. Thus if, as has been already stated, 2 pounds of water at 120° be mixed with 2 pounds at 60°, half the excess of caloric in the hot water will pass to the colder portion; that is, the hot water will be cooled 30°, and the cold will receive 30° of temperature; and, if the experiment be conducted with proper precautions, 90°, the arithmetical mean of the temperature of the separate parts, will be the temperature of the mixture. If 3 pounds of water at 100° be mixed with 1 pound at 60°, we shall have the same quantity of heat as before, *viz.*, 4 pounds at 90°. Hence if the quantity of water be multiplied by the temperature, the product will be a comparative measure of the quantity of caloric which the water contains, exceeding the zero of the thermometer employed.

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* Black's Lectures, i. 169.

Thus, in the last example,

3 × 100 = 300 = the caloric above zero in the first portion.
1 × 60 = 60 = the caloric above zero in the second ditto.

The sum, 360 = the caloric above zero in the mixture.

Dividing 360 by 4, the whole quantity of water, we obtain 90°, the temperature of the mixture.

This method of computation may be conveniently applied to a variety of cases. Thus, in the foregoing experiment, 8½ drachms of steam at 212°, added to 64 drachms of water at 50°, produced 72½ drachms of water at 173°. Now,

72½ × 173 = 12542½ = whole heat of the mixture.
64 × 50 = 3200 = heat of 64 drachms, one of the component parts.

9342½ = heat of 8½ drachms, the other component part.

Therefore 9342½ divided by 8½ = 1099, should have been the temperature of the latter portion (*viz.*, 8½ drachms), had none of its heat been latent; and 1099 — 212 = 887 gives the latent heat of the steam. This result does not differ more than might be expected, owing to the unavoidable inaccuracies of the experiment, from Mr. Watt's determination, which states the latent heat of steam, on an average of nine experiments, at 949.9°, say 950°.* Lavoisier, with the aid of the calorimeter, makes it 1000°, or a little more;† Mr. Southern [illegible], and Dr. Ure [illegible].

XIII. *The same weight of steam contains, whatever may be its density, the same quantity of caloric; its latent heat being increased, in proportion as its sensible heat is diminished; and the reverse.*—This principle, though scarcely admitting of illustration by any easy experiment, is one of considerable importance; and an ignorance of it has been the occasion of many fruitless attempts to improve the economy of fuel in the steam-engine. The fact, so far as respects steam of lower density than that of 30 inches of mercury, was first, I believe, determined experimentally by Mr. Watt.‡ As the boiling point of liquids is known to be considerably reduced by a diminished pressure, it seemed reasonable to suppose that, under these circumstances, steam might be obtained from them with a less expenditure of fuel. Water, Mr. Watt found, might easily be distilled *in vacuo* when at the temperature of only 70° Fahrenheit. But, by condensing the steam formed at this temperature, and observing the quantity of heat which it communicated to a given weight of water, he determined that its latent heat, instead of being only 950°, was between [illegible]

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* Black's Lectures, i. 174, [illegible]
† Ibid. i. 175. ‡ [illegible]

The same principle may be explained also by the following illustration, which was suggested to me by Mr. Ewart. Let us suppose that in a cylinder, furnished with a piston, we have a certain quantity of steam, and that it is suddenly compressed, by a stroke of the piston, into half its bulk. None of the steam will in this case be condensed; but it will acquire double elasticity, and its temperature will be considerably increased. Now if we either suppose the cylinder incapable of transmitting heat, or take the moment instantly following the compression before any heat has had time to escape, it must be evident that the sensible and latent heat of the steam, taken together before compression, are precisely equal to the sensible and latent heat taken together of the denser steam. But in the dense steam the sensible heat is increased, and the latent heat proportionally diminished. Reversing this imaginary experiment, if we suppose only half the cylinder to contain steam at 212°, and the piston to be suddenly raised to the top of the cylinder, the steam will be expanded to twice its volume, its temperature will fall, but its sensible and latent heat taken together will still remain unchanged. The explanation of these facts will be furnished by a principle to be hereafter explained, *viz.*, that the capacities of elastic fluids for caloric are uniformly diminished by increasing their density, and the reverse.

Direct experiments to ascertain the latent heat of steam, formed under higher pressures than that of the atmosphere, have been made by Mr. Southern of Soho, and by Mr. Sharpe, then of Manchester.* Those of the latter were first published, and were to him quite original. They were conceived and executed very ably, but were subsequent in point of time to the experiments of Mr. Southern, which, though only lately made public,† were instituted many years ago. The latter consisted in ascertaining the augmentation of weight and increase of temperature, gained by given quantities of water, from the condensation of known volumes of aqueous vapour of different densities. The results presented differences in the latent heat of steam of different densities, but of so very small an amount as to arise probably from unavoidable sources of error in manipulation. The following table exhibits the principal results obtained by Mr. Southern.

Temperature of Steam.	Elasticity of ditto in inches of Mercury.	Latent Heat.
229	40	942°
270	80	942°
295	120	950°

The experiments of Mr. Sharpe, and also a recent series by Clement and Desormes, (of which an abstract is given in the Appendix to Thenard's Traité de Chimie, vol. iv. p. 262, 3me edition,) establish the same general law, at least within certain limits. This law is of great importance in practice, since it shows that no essential saving of fuel can be reasonably expected from using, as a moving power, steam formed under high pressures: for as a pound of steam, of whatever density, gives out by condensation the same quantity of caloric, it is obvious that, to convert a pound of water into steam, will always require the same quantity of fuel, applied under equal circumstances, whatever may be the density of the steam which is produced. So far, indeed, from tending to economize fuel, it seems probable that the higher the temperature of the water in the boiler, the greater will be the loss of heat by the escape of hot air through the chimney. Nevertheless, there are certain cases in which high-pressure steam may be applied with great advantage to various manufacturing processes, as a means of communicating heat, when the temperature is required to exceed 212° Fahr.

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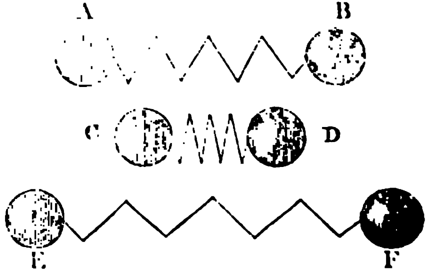
* Manchester Society's Memoirs, Vol. 2, New Series.

† Brewster's edition of Prof. Robinson's Works.

A remarkable fact has been observed respecting steam of great elasticity, *viz.*, that when suffered to escape suddenly from a cock or small aperture in the boiler, the hand may be held close to the orifice from which the steam is issuing violently, without being scalded by it, though every one knows that steam of ordinary density scalds severely under the same circumstances. On applying a thermometer to the steam escaping from the boiler, its temperature is found to be considerably reduced: for instance, steam, which, within the boiler, was at 290° Fahr., falls suddenly, when let out, to 160°. That it should fall to 212° would not be surprising, since that is the temperature of steam under the ordinary pressure of the atmosphere; but it is difficult to conceive why it should descend 52° below 212°. Of this fact, Mr. Ewart has given an ingenious, and, it appears to me, a satisfactory, explanation, founded on the results of experiments, which he has described in the Annals of Philosophy for April 1829. He supposes that the particles of elastic fluids have a tendency, when they are forced near to each other, to fly asunder, not only to their original distance, but beyond it. To illustrate this, let us suppose two equal balls of lead, A B, to be connected by an elastic steel spring, in a perfectly neutral state, so that they have no tendency either to collapse or expand. Compress them nearer to each other, as C and D, and, suddenly setting them at liberty, they will separate, not merely to their original distance, but beyond it, as at E and F. Now, if we suppose A B to represent two atoms of steam, of air, or of any elastic fluid, compressed as C D, and suddenly liberated, they will, by the combined action of their elasticity and momentum, separate to E F, or thereabouts. Thus high-pressure steam, on suddenly taking off all pressure beyond that of the atmosphere, is converted into low-pressure steam, and its temperature falls, in con-



sequence of the law which connects the rarefaction of elastic fluids with an absorption of caloric. It is quite in accordance with this theory that the more strongly steam is compressed, the more dilated and the colder it is on being suddenly released from pressure.

XIV. *Conversion of Liquids into Vapours under strong Pressure.*—It is well known that by means of a Papin's digester we are enabled to raise the temperature of liquids considerably above the points, at which they boil under the mean pressure of the atmosphere; and it seemed probable that the internal pressure, augmenting with the temperature, must effectually prevent the total volatilization of the liquid, especially if the space, left above the liquid, is not of a certain extent. But provided sufficient space is allowed for the generated vapour, it appeared to Mr. Cagniard de la Tour a necessary consequence, that there should be a limit beyond which these liquids ought, notwithstanding the pressure, to be completely volatilized; and to verify this opinion he was led to make some interesting experiments.

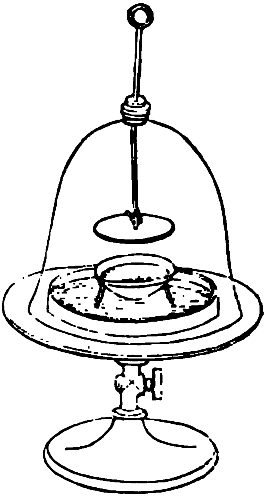
A strong glass tube, containing about two-fifths its capacity of alcohol, sp. gr. .837, being carefully heated, the alcohol continued to expand, till, after having attained nearly double its original volume, it was converted into vapour so transparent, that the tube appeared completely empty. Allowing it to cool, the alcohol was again condensed into a liquid. When the proportion of alcohol to the capacity of the tube was increased, the consequence was the bursting of the tube. Similar results were obtained with naphtha and ether, the latter requiring less space than the former for being converted into vapour without breaking the tube; and naphtha less space than alcohol. No difference was occasioned by the presence of atmospheric air in the tubes, or its exclusion from them, except that the ebullition of the liquid was then much more moderate.

The same success did not attend the first attempt to convert water into vapour; for when a tube, about one-third filled with water, was similarly heated, it burst with an explosion. The inner surface of the glass tube appeared also to have been acted upon, its transparency being impaired.

M. de la Tour afterwards determined the densities of these vapours, by means of a gauge which measured the bulk of a confined portion of air, subjected, through the intervention of a column of quicksilver, to the pressure of the generated vapour. Alcohol converted into vapour, and occupying a space a little exceeding three times the volume of the original liquid, he found to exert a pressure = 119 atmospheres, and to require a temperature of 404.6° Fahrenheit. Ether, under the same circumstances, required a temperature of 369° Fahrenheit, and the force of its vapour was equivalent to 37 or 38 atmospheres; bisulphuret of carbon required 527° Fahrenheit, and the pressure of its vapour was equal to 78 atmospheres. Water, to which a minute quantity of carbonate of soda had been added, ceased to act upon glass tubes; and, though several tubes were broken, it was ascertained that water itself may be converted into vapour, provided the vacant space exceed its volume about four times. (Annales de Chimie et de Phys. xxi. 127, 178, xxii. 410, or Ann. of Philos. v. 290.)

XV. *The evaporation of water is carried on much more rapidly under a diminished pressure, especially if the vapour, which is formed, be condensed as soon as it is produced, so as to maintain the vacuum.* On this principle depends Mr. Leslie's new and ingenious mode of freezing water, in an atmosphere of any common temperature, by producing a rapid evaporation from the surface of the water itself. The water to be congealed is contained in a shallow vessel, which is supported above another vessel, containing strong sulphuric acid, or dry muriate of lime, or even dried garden mould or parched oatmeal. Any substance, indeed, that powerfully attracts moisture, may be applied to this purpose. The whole is covered by the receiver of an air-pump, which is rapidly exhausted; and, as soon as this is effected, crystals of ice begin to shoot in the water, and a considerable quantity of air makes its escape, after which the whole of the water becomes solid. The rarefaction required is to about 100 times; but to support congelation, after it has taken place, 20 or even 10 times are sufficient. The sulphuric acid becomes very warm; and it is remarkable, that if the vacuum be kept up, the ice itself evaporates. In five or six days, ice of an inch in thickness will entirely disappear. The acid continues to act till it has absorbed an equal volume of water.

An elegant manner of making the experiment is to cover the vessel of water with a plate of metal or glass, fixed to the end of a sliding wire, which must pass through the neck of the receiver, and be, at the same time, air-tight, and capable of being drawn upwards. (See the annexed figure.) The receiver being exhausted, the water will continue fluid, till the cover is removed, when, in less than five minutes, needle shaped crystals of ice will shoot through it, and the whole will soon become frozen. If this should not happen, a slight but smart blow, given to the air-pump, will often occasion immediate congelation.



In this interesting process, if it were not for the sulphuric acid, an atmosphere of aqueous vapour would fill the receiver; and this, pressing on the surface of the water, would prevent the further production of vapour. But the steam which rises, being condensed the moment it is formed, the evaporation goes on very rapidly, and has no limits but the quantity of the water, and the diminished concentration of the acid.[*]

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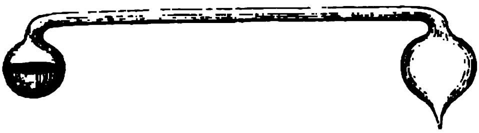
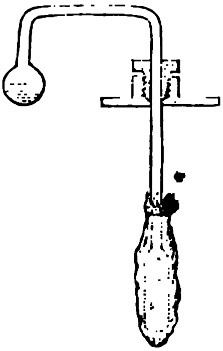
[*] The most complete account of this new mode of freezing is to be found in the Supplement to the Encycl. Brit. Art. COLD.

It is on the same principle that the instrument invented by Dr. Wollaston, and termed by him the *Cryophorus*, or *Frost-bearer*, is founded. It may be formed by taking a glass tube, having an internal diameter of about ⅛th of an inch, the tube being bent to a right angle, at the distance of half an inch from each ball, thus:



One of these balls should be about half filled with water, and the other should be as perfect a vacuum as can readily be obtained, the mode of effecting which is well known to those accustomed to blow glass. One of the balls is made to terminate in a capillary tube; and when the water in the other ball has been boiled over a lamp a considerable time, till all the air is expelled, the capillary extremity, through which the steam is still issuing with violence, is held in the flame of the lamp, till the force of the vapour is so far reduced that the heat of the flame has power to seal it hermetically.

When an instrument of this kind is well prepared, if the empty ball be immersed in a mixture of snow and salt, the water in the other ball, though at the distance of two or three feet, will be frozen solid in the course of a very few minutes. The experiment may be rendered still more striking, if performed according to Dr. Marcet's modification of it: the empty (lower) ball, covered with a little moist flannel, is to be suspended, in the manner shown by the annexed sketch, within a receiver, over a shallow vessel of strong sulphuric acid, and the receiver is then to be exhausted. In both cases, the vapour present in the empty ball is condensed by the operation of cold; and the vacuum, produced by this condensation, gives opportunity for a fresh quantity to arise from the opposite ball, with a proportional reduction of the temperature of its contents.



An ingenious application of the fact that evaporation takes place *in vacuo*, at a lower temperature than under common pressures, was made by the late Mr. Edward Howard, to the concentration of syrup in the process of refining sugar. The syrup, in his method, is enclosed in an air-tight vessel, from which the atmospheric air is extracted mechanically by a pump, and the evaporation, therefore, goes on at a low degree of heat, which secures the syrup from injury. (Repertory of Arts, series 2, vols. 23 and 25.) Mr. J. J. Barry obtains a vacuum in a cheaper and easier manner, by the condensation of steam, applied in a way which would not be understood without a plate, and of which it may be sufficient to say that he can maintain, in the liquid to be evaporated, a steady temperature of from 90° to 100° Fahr. Mr. Barry's process is peculiarly adapted to the preparation of medicinal extracts, the active portion of which is liable to be decomposed at a heat considerably below that of boiling water. (See Transact. of the Medico-Chirurg. Soc. of London, vol. 10.)

The large quantity of caloric, latent in steam, renders its application extremely useful for practical purposes. Thus, water may be heated, at a considerable distance from the source of heat, by lengthening the conducting pipe *e*, fig. 46. This furnishes us with a commodious method of warming the water of baths, which, in certain cases of disease, it is of importance to have near the patient's bed-room; for the boiler, in which the water is heated, may thus be placed on the ground-floor, or in the cellar of a house, and the steam conveyed by pipes into an upper apartment. Steam may also be applied to the purpose of heating or evaporating water, by a modification of the apparatus. Fig. 46, *g*, represents the apparatus for boiling water by the condensation of steam, without adding to its quantity, a circumstance occasionally of considerable importance. The steam is received between the vessel, which contains the water to be heated, and an exterior case; it imparts its caloric to the water, through the substance of the vessel; is thus condensed, and returns to the boiler by the perpendicular pipe. An alteration of the form of the vessels adapts it to evaporation (fig. 46, *h*.) This method of evaporation is admirably suited to the concentration of liquids, that are decomposed, or injured, by a higher temperature than that of boiling water, such as medicinal extracts; to the drying of precipitates, &c. In the employment of either of these vessels, it is expedient to surround it with some slow conductor of heat. On a small scale, a few folds of woollen cloth are sufficient; and, when the vessel is constructed of a large size for practical use, this purpose is served by the brickwork in which it is placed.

SECTION V.

Caloric the Cause of permanently elastic Fluidity.—General Properties of Gases.

From the facts which have been detailed in the last section, it appears that in vapours, strictly so called, such as the steam of water, caloric is retained with but little force; for it quits the water when the vapour is merely exposed to a lower temperature. But, in permanently elastic fluids, caloric is held very forcibly, and no diminution of temperature, that has ever yet been effected, can separate it from some of them. Thus the air of our atmosphere, in the most intense artificial or natural cold, still continues in the aëriform state. Hence is derived one character of gases, *viz.*, that they remain aëriform under almost all variations of pressure and temperature, and in this class are also included those aërial bodies, which, being immediately condensed by contact wih water, require confinement over mercury. The following experiment will show that the caloric contained in gases is chemically combined, or at least that it is inappreciable by the thermometer.

Into a small retort (plate ii. fig. 26, *b*) put an ounce or two of well dried common salt, and about half its weight of sulphuric acid. By this process, a great quantity of gas is produced, which might be received and collected over mercury. But, to serve the purpose of this experiment, let it pass through a glass balloon, *c*, having three openings, into one of which the neck of the retort passes, while from the other, a tube, *e*, proceeds, which ends in a vessel of water, *f*, of the temperature of the atmosphere. Before closing the apparatus, let a thermometer, *d*, be included in the balloon, to show the temperature of the gas. It will be found that the mercury, in this thermometer, will rise only a few degrees, whereas the water, in the vessel which receives the bent tube, will soon become almost boiling hot. In this instance, caloric flows from the lamp to the muriatic acid, and converts it into gas; but the heat, thus expended, is not indicated by the thermometer. The caloric, however, is again evolved, when the gas is condensed by water. In this experiment, we trace caloric into a latent state, and again into the state of free or uncombined caloric.

For demonstrating the influence of variations of atmospheric pressure on the *formation* of gases, better experiments cannot be devised than those of Lavoisier.* But, as some students, who have the use of an air-pump, may not possess the apparatus described by Lavoisier (the glass bell and sliding wire), it may be proper to point out an easier mode of showing the same fact. This proof is furnished by the experiment already described, in which sulphuric ether is made to assume alternately an aëriform and liquid state, by removing and restoring the pressure of the atmosphere.

It was long ago suggested by Mr. Dalton (Manch. Soc. Mem. v. 550,) that all gases are convertible into liquids. "There can scarcely," he observes, "be a doubt entertained respecting the reducibility of all elastic fluids, of whatever kind, into liquids; and we ought not to despair of effecting it in low temperatures, and by strong pressure, exerted upon the unmixed gases." It fortunately occurred to Mr. Faraday that the most probable means of exhibiting gases (or rather what, under ordinary circumstances, would be such) in the liquid state, would be to *generate* them under strong pressure; and his experiments have confirmed this sagacious conjecture. When thus produced in strong glass tubes, they continued liquid at low temperatures, while the pressure was kept up, but, on removing the pressure, instantly passed into the gaseous state. Some of them evinced so strong a tendency to become permanently elastic, that the tubes containing them exploded spontaneously, with great violence, by a slight increase of the temperature of the atmosphere. The gases thus liquefied were chlorine, euchlorine, sulphureted hydrogen, nitrous oxide, cyanogen, ammonia, and muriatic, sulphurous, and carbonic acids. The last-mentioned fluid required for its confinement much stronger tubes than any of the others, and produced the most violent and dangerous explosions. (Phil. Trans. 1823, p. 161, 189.) The liquids thus produced may probably, as Sir H. Davy has suggested, become most powerful mechanical agents; and experiments with this view were, some time ago, put in train by M. Brunel, (Quart. Journ. xxi. 131,) the results of which have not yet been published.

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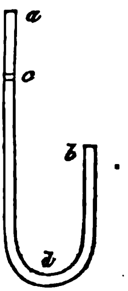
* See his Elements, chap. i.

Gases, when once formed, undergo a considerable change of bulk by variations of external pressure. The general law, first, I believe, established on this subject, by Mariotte, is, that the *volume of gases is inversely as the compressing force.* If, for example, we have a quantity of gas, occupying, under the common pressure of the atmosphere, 60 cubic inches, it will fill the space of only 30 cubic inches, or one half, under a double pressure; of 20 inches, or one third, under a triple pressure; of 15 inches, or one fourth, under four times the pressure; and so on.

These results, so far as respects the more permanent gases, have been confirmed by Oersted, (Quart. Journ. xxii. 198) who carried the compression of air as far as 110 atmospheres. But, with respect to some of the more easily liquefiable gases, Despretz has found that they deviate sensibly from Mariotte's law. This is the case with sulphureted hydrogen, sulphurous acid, cyanogen, and ammonia, even when completely deprived of hygrometric moisture. (Ann. de Ch. et Phys. xxxiv. 335, 443.)

The law of the *dilatability of gases by heat* has already been stated to be an enlargement of about $\frac{1}{480}$th part of their bulk for each degree of Fahrenheit's scale, between the freezing and boiling points of water. It is, however, necessary, that the gases submitted to experiment should be perfectly deprived of aqueous vapour. These expansions, it has been shown by Sir H. Davy, continue exactly the same in dry compressed air, at temperatures between 32° and 212°, and also in air confined by columns of quicksilver, whether the air was $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{6}$ of its natural density. (Phil. Trans. 1823, p. 204.)

All gases exhibit a reduction of their temperature by mechanical rarefaction, and an evolution of heat by condensation, of their volume. It had long been known, that, if a thermometer be enclosed in receiver, and the air be suddenly condensed, the thermometer rises and, if the air be rapidly exhausted, it falls, but in each case only a few degrees above or below the temperature of the atmosphere. Mr. Dalton, struck with the *suddenness* of the rise or fall, was the first to suspect that the change of temperature is, in each case much greater than is indicated by the mercurial thermometer. He contrived, therefore, a very simple and beautiful method of determining the real amount of the change. With this view, he took large receiver, and enclosed in it a graduated tube, one-fifteenth of an inch diameter, bent syphonwise, as in the figure, sealed at the end *b*, and open at the extremity *a*. Within the tube was a shor



column of mercury, c, the rise or fall of which, by any change of elasticity of the air in the tube, or in the receiver, rendered it a proper *manometer*, or *measurer of rarefaction*. He next doubled the density of the air in the receiver, and of course the mercurial column was forced down till the air in the closed part of the syphon occupied only half its original bulk. Then, suddenly opening the cock attached to the receiver, the mercurial column ran up quickly to its former station. At this moment the cock was suddenly shut, which caused the mercurial column again to fall down gradually for five or ten seconds, to the amount nearly of one-tenth of the column of air included in the manometer, when it became stationary. Once more opening the cock, air rushed out of the receiver, and the mercury regained its position at *c*.

When the experiment was reversed, by exhausting a receiver, under which the same manometer was placed, with the mercurial column stationed at the commencement at *d*, the phenomena took place in a reversed order. At first the mercury rose to *c*; on opening the cock it fell to *d*; on shutting, it retrograded towards *c*; and, on again opening the cock, established itself at *d*.

These facts, which, though observed only with respect to atmospheric air, would no doubt take place with some variation in all gases, are explained by Mr. Dalton in the following manner. The air in the receiver, and that in the manometer, are subject to a like degree of condensation or rarefaction, or very nearly so. When the equilibrium of heat is disturbed by condensing or expanding the air, it is restored in that within the manometer instantly, by reason of the extensive surface of glass to which that air is exposed. But, in the large receiver, a sensible time, of ten seconds or more, is required to restore the equilibrium through its whole capacity. It is this restoration that increases or diminishes the elasticity of the air in the receiver, and thereby causes the mercurial column to retrograde. Now it is ascertained, that, to contract or expand a portion of air by one-tenth of its volume, a change of temperature equal to 50° Faht. is required. It follows, therefore, that in the case of restoring the equilibrium of condensed air, about 50° of cold are produced, and, in letting air into an exhausted receiver, 50° of heat are evolved. The phenomena, Mr. Dalton ascertained, are independent of aqueous vapour, and are more remarkable in dry than in humid air. They depend on the diminished capacity of air for heat by condensation, and its increased capacity by rarefaction, and are common to all gases; but, as will appear when we come to speak of the specific heat, vary, as to their extent, in different gases.

When air (and no doubt any other gas) is suddenly and forcibly compressed, in a syringe for instance, the quantity of caloric liberated by the first stroke of the piston is sufficient to set fire to a piece of the tinder called *amadou*. A flash of light is also perceptible at the moment of condensation, in an instrument adapted for showing it, by a glass bottom. This fact has been applied to he construction of a portable instrument for lighting a candle, consisting of a common syringe, at the bottom of which is a small chamber for containing the tinder. The condensation of the air by a smart stroke of the piston produces sufficient heat to set the tinder on fire. (Phil. Mag. vols. 14, 31, and 40.)

All gases, by contact with water, become mingled with aqueous vapour, the proportion of which is regulated by the temperature and pressure to which the gases are subjected; but, those circumstances being equal, *the proportion of aqueous vapour is the same in every gas.* This subject will be resumed in treating of atmospheric air. At present it may be sufficient to observe that moisture may be absorbed from gases by substances that strongly attract water, such as quicklime, chloride of calcium which has been recently fused, sulphuric acid, &c.; but, to effect this, it is necessary that the gas should be confined, in contact with the absorbent substance, over well dried mercury. When a glass vessel, containing any gas not artificially deprived of its moisture, is cooled below the temperature of the atmosphere, moisture is condensed in small drops, or, if a freezing mixture be applied, in the form of a thin film of ice, on the inner surface of the vessel. The steam present in gases is also rendered visible, by suddenly expanding or suddenly condensing their volume. In the first case, the reduction of temperature which takes place, amounting, as has been shown, to 50° Faht., robs the aqueous vapour of its constituent heat. In the second, the diminution of space, essential to the existence of vapour, causes the precipitation of water, notwithstanding the temperature evolved by condensing the air.

When a body, heated to a certain point, is placed in different gases, under circumstances otherwise similar, it is found to cool with very different velocities; in other words, the *power of elastic fluids to conduct heat differs for different gases.* Dr. Priestley appears to have been quite aware of this; Mr. Dalton has given a series of experiments on this subject; and Sir H. Davy, having raised the same thermometer to the same temperature, 160° Fahr., exposed it to equal volumes (21 cubic inches) of the following gases at 52° Fahr.

The times for cooling down to 106° were for

	Min.	Sec.		Min.	Sec.
Atmospheric air - -	2	0	Oxygen - - - - - -	1	47
Hydrogen - - - - -	0	45	Nitrous Oxide - - - -	2	30
Olefiant gas - - - - -	1	15	Carbonic Acid - - - -	2	45
Coal gas - - - - - -	0	55	Chlorine - - - - - -	3	6
Azote - - - - - - -	1	30			

It appears from this Table, that the powers of elastic fluids to abstract or conduct away heat from solid surfaces is in some inverse ratio to their density. The nature of the surface of the hot body, it has been shown by Dulong and Petit, does not affect the conducting power of gaseous bodies; but the state of the gases themselves, as to moisture or dryness, has a considerable influence; for moist gases, as is shown by Count Rumford's experiments, conduct heat much more rapidly than dry ones. Differences, however, in the *specific heats* of gases (if such differences really exist) must render it difficult to determine how much of the effect is owing to that cause, and how much to a real difference of conducting power.

Before dismissing the consideration of the gases in general, there are a few properties, which it may be proper to notice, with the view of comparing the degree in which they belong to different individuals of the class.

I. The exact *specific gravity* of the different gases is a most important element, in calculating the proportion of the ingredients of compounds, into which they enter. Nothing, indeed, can show the importance of this object more strikingly than the fact, that on the precise specific gravities of hydrogen and oxygen gases, depend the whole series of numbers, which are used to express the weights of the atoms of bodies on the Daltonian theory. The following Table exhibits the specific gravities of the most important bodies of this class.*

TABLE OF THE SPECIFIC GRAVITY OF GASES.†

Barometer 30. Thermometer 60°.

NAMES OF GASES.	Specific gravity.	Weight of 100 cubic inches.	AUTHORITIES.
		Grains.	
Atmospheric air	1.0000	30.50	Shuckburgh.
Ditto	1.0000	30.199	Brande.
Ditto		†31.	Prout and Dalton.
SIMPLE GASES AND VAPOURS.			
Oxygen	1.1088	33.82	Allen and Pepys.
Ditto	1.1111	33.888	Thomson.
Ditto	1.1026	33.629	Berzelius and Dulong.
Chlorine	2.5082	76.500	Davy.
Ditto	2.5000	76.250	Thomson.
Iodine (vapour)	8.678	244.679	Gay Lussac.
Ditto	8.6111	262.6308	Thomson.
Hydrogen	0.0694	2.116	Ditto.
Ditto	0.0688	2.098	Berzelius and Dulong.
Nitrogen	0.9722	29.652	Thomson.
Ditto	0.9760	29.768	Berzelius and Dulong.
Carbon (vapour)	0.4166	12.6083	Gay Lussac.
Sulphur (ditto)	1.1111	33.888	Thomson.
Phosphorus (ditto)	0.8333	25.416	Ditto.

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* Gay Lussac's Table, which is more copious, but in which the numbers are not reduced to a mean of the barometer and thermometer, is copied into Thomson's Annals, ix. 16; a Table by Professor Meinecke of Halle is inserted in the Journal of Science, &c. iii. 415. Dr. Thomson's elaborate paper on this subject is printed in the 16th volume of Annals of Philosophy; and Berzelius and Dulong's in the 15th volume of Annales de Chim. et de Physique.

† The figures in the second column will, of course, require to be altered, if 100 cubic inches of atmospheric air should be shown to weigh 31 grains, not 30.5, as hitherto allowed.

Table of Gases continued.

NAMES OF GASES.	Specific gravity.	Weight of 100 cubic inches.	AUTHORITIES.
COMPOUND COMBUSTIBLES.		Grains.	
Ammonia - - - - - - - - -	0.5960	18.18	Allen and Pepys.
Ditto - - - - - - - - - -	0.5902	18.003	Thomson.
Ditto - - - - - - - - - -	0.5912	18.03	Berzelius and Dulong.
Carbureted hydrogen - - - -	0.5555	16.944	Thomson.
Ditto - - - - - - - - - -	0.5590	17.049	Berzelius and Dulong.
Olefiant - - - - - - - -	0.9722	29.652	Thomson.
Ditto - - - - - - - - - -	0.9804	29.90	Berzelius and Dulong.
Phosphureted hydrogen - - -	0.9027	27.537	Thomson.
Bi-hydroguret of phosphorus -	0.9722	29.652	Ditto.
Sulphureted hydrogen - - -	1.1805	36.007	Ditto.
Bi-sulphuret of carbon (vapour)	2.6388	80.486	Ditto.
Arsenureted hydrogen - - -	0.5290	16.130	Tromsdorff.
Cyanogen - - - - - - -	1.8055	55.069	Gay Lussac.
Ditto - - - - - - - - - -	1.8188	55.473	Berzelius and Dulong.
Ether sulphuric (vapour) - -	2.5808	78.714	Ditto.
Ether muriatic (ditto) - - -	2.2190	67.679	Thomson.
Ether hydriodic (ditto) - - -	5.4750	166.987	Ditto.
Ether chloric (ditto) - - - -	3.4750	105.257	Ditto.
Alcohol (ditto) - - - - - -	1.6004	48.812	Berzelius and Dulong.
Turpentine, oil of (ditto) - - -	5.0130	152.896	Gay Lussac.
OXIDES.			
Aqueous vapour - - - - -	0.6250	19.062	Gay Lussac.
Nitrous oxide - - - - - -	1.5277	46.597	Thomson.
Ditto - - - - - - - - - -	1.5273	46.582	Berzelius and Dulong.
Nitric oxide - - - - - - -	1.0416	31.770	Thomson.
Carbonic oxide - - - - - -	0.9722	29.652	Ditto.
Ditto - - - - - - - - - -	0.9727	29.667	Berzelius and Dulong
ACIDS.			
Carbonic - - - - - - - - -	1.5277	46.597	Thomson.
Ditto - - - - - - - - - -	1.5240	46.481	Berzelius and Dulong
Chlorocarbonic (Phosgene) - -	3.4722	105.902	Thomson.
Chlorocyanic (vapour) - - -	2.1520	65.636	Ditto.
Fluoboric - - - - - - - -	2.3611	72.013	Ditto.
Fluo-silicic - - - - - - -	3.611	110.138	Ditto.
Hydriodic - - - - - - - -	4.340	132.378	Ditto.
Hydro-cyanic (vapour) - - -	0.9375	28.572	Ditto.
Hyponitrous - - - - - - -	2.6382	80.465	Theory.
Muriatic - - - - - - - -	1.2847	39.183	Thomson.
Nitrous acid - - - - - - -	3.1943	97.426	Theory.
Nitric - - - - - - - - - -	3.75	114.375	Sir H. Davy.
Sulphurous - - - - - - -	2.2222	67.777	Thomson.
Sulphuric (vapour) - - - -	2.7777	84.698	Ditto.

To the above table, I consider it desirable to annex another, lately deduced by M. Dumas from an ingenious and elaborate set of experiments, which form the subject of his memoir *On some Points of the Atomic Theory*, published in the Ann. de Chim. et de Physique, xxxiii. 337.

F THE DENSITIES (OR SPECIFIC GRAVITIES) OF CERTAIN VAPOURS AND GASES. (AIR = 1.)

ME OF VAPOUR OR GAS.	Density by Experiment.	Density by Calculation.
	8.716	8.6118
	6.976	6.9783
ride of phosphorus	4.875	4.8076
ed hydrogen	2.695	2.695
of silicium	5.9390	5.9599
ric acid	3.600	3.5973
of boron	3.942	4.0793
acid	2.3124	2.3075
de of tin	9.1997	8.993
de of titanium	6.836	7.047
us		2.2052
		5.1839
		1.0197
		0.7487
		4.053
		2.107

olid bodies, that possess a certain degree of porosity, are absorbing gases. This was first observed in charcoal, of which to condense different gases will be fully described section on that substance. It has been found, also, by jun. to belong to a stone called meerschaum, to adhesive stos, rock cork, and other minerals; and to raw silk and following general principles are deducible from the experiments of Saussure.*

necessary to deprive the solid of the air which it contains. When of a nature not to be injured by heat, this ectually done by igniting the solid, and quenching it unry, where it is to be kept, till admitted to a given volume to be absorbed. Solids that are decomposable by heat prived, though less effectually, of air, by placing them ceiver, which must then be exhausted by the air-pump.

same solid absorbs different quantities of different gases. for instance, condenses 90 times its bulk of ammoniacal ot quite twice its bulk of hydrogen.

s, chemically the same, absorb different quantities of the according to their state of mechanical aggregation. dense charcoal of box-wood absorbed 7½ volumes of air, ht charcoal, prepared from cork, did not absorb a sen-ity.

rent solids absorb different quantities of the same gas; ty of carbonic acid absorbed by charcoal being about s greater than that absorbed by meerschaum.

n the solid exerts no chemical action on the gas, the ab- terminated in 24 or 36 hours.

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* Annals of Philosophy, vi. 241.

6. The effect of moistening the solid is to retard the absorption and to diminish its amount; and when a gas has actually been absorbed, it is again driven out unchanged, partly by water of the ordinary temperature, and entirely by exposure to a boiling heat.

7. During the absorption of a gas by a solid, the temperature of the latter rises several degrees, and this rise bears a proportion to the absorbability of the gas, and the rapidity with which it is condensed.

8. Solids condense a greater number of volumes of the more absorbable gases, under a rare than under a dense atmosphere; but if the absorption be reckoned by weight, it is most considerable under the latter state.

9. When a solid saturated with any one gas is introduced into an atmosphere of any other gas, a portion of the first is expelled, and a part of the second takes its place.

III. *Gases are absorbed by liquids.* On this subject the following general principles may be laid down.

1. The same liquid absorbs different quantities of different gases. Thus water takes up its own bulk of carbonic acid, and not one-fiftieth of its bulk of hydrogen gas.

2. Different liquids absorb different quantities of the same gas. Alcohol, for instance, absorbs almost twice as much carbonic acid, as is taken up by an equal volume of water.

3. The absorption is promoted by first freeing the liquid from air, either by long continued boiling in a vessel with a narrow neck, or by the air-pump. It requires, also, brisk and long continued agitation, especially with the less absorbable gases.

4. It does not appear that the gases are absorbed by all liquids in the same order. For example, of four gases, naphtha absorbs most olefiant gas; oil of lavender most nitrous oxide; olive oil most carbonic acid; and solution of muriate of potassa most carbonic oxide.

5. The viscidity of liquids, though it does not much influence the amount absorbed, occasions a longer time to be spent in effecting the absorption. On the other hand, the amount of any gas, which is absorbed by water, is diminished by first dissolving in the water any saline substance.

6. In general, the lightest liquids possess the greatest power of absorbing gases; whereas, when there is no evident chemical action, the heaviest gases are absorbed most copiously and rapidly by the same liquid.

7. The temperature of a liquid is raised by the absorption of a gas, in proportion to the amount and the rapidity of the absorption.

8. In all liquids the quantities of gases absorbed are directly as the pressure. For example, a liquid, which absorbs its own bulk of gas under the pressure of the atmosphere, will still absorb its own bulk of the same gas under double, triple, &c. pressure; but its own bulk of gas, twice compressed, is equal to double its bulk of gas ordinarily compressed, and so on. The proofs of this law I have given at length in the Philosophical Transactions for 1803.

9. When water, or probably any other liquid, is agitated with

a limited quantity of any mixture of two gases, it does not absorb one gas to the exclusion of the other, but absorbs a portion of both. In this case, the density of each gas in the water or liquid has a constant relation to that without, *for the same gas.* Thus in carbonic acid gas, the density is the same within and without the water; in olefiant gas and phosphureted hydrogen, the density within is 1-8th of that without; in oxygen and carbureted hydrogen, &c. the density within is 1-27th of that without; in azote and hydrogen, it is about 1-50th, according to Dalton, though he originally stated it to be 1-64th, under the impression that the distances of the particles within were always some multiple of those without. This concise enunciation of the general law, deduced by Mr. Dalton from his experimental inquiries, will be better understood by the illustrations contained in a paper published in the Annals of Philosophy, vii. 216, where the reader will find a formula for ascertaining the quantities of mixed gases absorbed by water.

The principle, on which gases are absorbed and retained by liquids, has been a subject of controversy. By Berthollet, Thomson, Saussure, and the generality of chemists, it is ascribed, in all cases, to the exertion of a chemical affinity between the gas and the liquid; but it is contended by Mr. Dalton and myself that the effect in most cases is chiefly, if not wholly, mechanical. The discussion would lead me into details of too great a length; and I refer, therefore, for a full statement of the argument, to two papers which I published in the 8th and 9th volumes of Nicholson's Journal: to Mr. Dalton's New System of Chemical Philosophy; and to his essay, in the 7th volume of Dr. Thomson's Annals, which contains a reply to the objections advanced against the mechanical theory by Saussure, in the 6th volume of the same work. This reply seems to have unaccountably escaped the notice of several writers, (Berzelius, for instance,) who continue to urge the objections of Saussure, after they have been fully and satisfactorily answered by Mr. Dalton. An essay, by Mr. Graham, on the absorption of gases by water, in the 12th vol. N. S. of Ann. of Phil., is, however, deserving the reader's attention.

IV. *Gases have a mutual tendency to diffusion through each other.* This operates to such a degree, that, if two different gases are placed in communication, either with large surfaces, or by a narrow tube connecting two receivers, each containing a different gas, they are found, after a sufficient time, to be intimately mixed. This happens even when the gases have very different specific gravities. In this case the lighter, though placed uppermost at first, gradually descends, and mixes with the heavier, and the reverse. A striking instance of this kind will be given in speaking of hydrogen gas. From the observations of Mr. Faraday, it appears that gases kept over mercury, or in bottles closed by well ground stoppers, gradually exchange places with the external atmosphere, and are not to be relied on for their purity after a long interval of time. (Quart. Journ. xxii. 220.)

V. The velocities with which different gases, when condensed artificially by the same degree of pressure, escape through a capillary tube, has been shown by Mr. Faraday to vary very considerably. (Quart. Journal, iii. 354, vii. 106.) The following table exhibits the comparative times required by some of the gases to escape from a vessel in which they were all equally compressed at the outset, till their density arrived at an atmosphere and a quarter.

Carbonic acid required - - - - - -	156.5 minutes.
Olefiant gas - - - - - - - - - - -	135.5
Common air - - - - - - - - - - -	128
Coal gas - - - - - - - - - - - -	100
Hydrogen - - - - - - - - - - - -	57

These differences cease to exist at low pressures; for equal volumes of hydrogen and olefiant gases passed through the same tube, at equal low pressures, in almost the same time. Through small needle holes, hydrogen gas, pressed by a small column of mercury, escaped about three times more quickly than olefiant gas. Increasing the pressure, the same proportions were observed; and also, though not to the same degree, when the gases were expelled through slits cut by a penknife. Both glass and metal tubes produced the effect, and it was heightened as the gas was made to pass more slowly through the tube, and this whether the increased time was caused by diminished pressure, increased length of tube, or diminished diameter. The specific gravity of the gases seems to have no influence, for carbonic acid, olefiant, and oxygen gases, under the same pressure and other equal circumstances, required respectively 4′ 6″, 5′ 5″, and 5′ 45″, for the escape of the same quantity of gas; numbers, as will be seen from the foregoing Table of Specific Gravity of Gases, bearing no proportion to their relative weights. What is singular in these results is, that the ratio for the same gas varies with the pressure, and that this variation differs in different gases. Thus the one which passes with the greatest facility at low pressures, passes with the least at high pressures.

This investigation has been pursued and extended by M. Girard. (Ann. de Chim. et de Phys. xvi. 129.) He was permitted to use, for his experiments, the gazometer and pipes belonging to one of the gas lighting establishments at Paris. The gases operated upon were common air, and carbureted hydrogen, which, when allowed to escape at different distances from the gazometer, through equal apertures in a three inch pipe, and under the same pressure, gave the following results:

The distances being - - - - - -	1288, 3758, 6228
The quantities of carb. hyd. were -	1281, 710, 541
Ditto of common air - - - -	902, 541, 394

The escape of carbureted hydrogen, therefore, considerably exceeded that of common air, but not in proportion to its inferior specific gravity, which is not much more than half that of the atmosphere, while the excess in the escape of the lighter gas is far from being double that of the heavier. Similar results were obvhen the gases were expelled through tubes of 7 lines in r, or through an aperture in the side of the gazometer, the gas being discharged in both cases the most abundantly. itter case, each gas escaped 11 times faster than when it raverse a tube of the same diameter as the hole, and 127 n length. In all cases, equal quantities of gas, in any one ent, escaped in equal times.

phenomena of the movement of gases through pipes, M. hows, are exactly the same as those of the linear move- incompressible fluids; and he draws several conclusions, re important to those practically engaged in operations juire the transmission of gases through long tubes; for however, I must refer the reader to the memoir itself.

The *colour of the electric spark*, when transmitted through different gases, has been observed by De Grotthus[*] to be as follows: nospheric air of double density, the spark was more brilt not coloured.

ıydrogen gas - - - - - - - - - - - -	purple.
›hosphureted hydrogen - - - - - - -	red.
ımmonia - - - - - - - - - - - - -	red.
lry carbonic acid gas - - - - - - - -	violet.
ɔxygen gas - - - - - - - - - - - -	ditto.
aqueous vapour - - - - - - - - - - -	orange.
vapour of ether } litto of alcohol } - - - - - - - - - -	celadon green.

eneral inference from his experiments is, that the intensictric light is always in a direct proportion to the density as, and in the inverse proportion to the conducting power as for electricity.

The *comparative soniferous properties of the gases* have been ied by Messrs. Kerby and Merrick; but, as these belong › mechanical than to chemical science, I shall content my- ı referring to the account of them in the 27th and 33d vo- Nicholson's Journal, and in the 45th volume of the Phial Magazine; and to Mr. Leslie's paper on sounds excited gen gas. (Ann. of Phil. N. S. iv. 172.)

SECTION VI.

Specific Caloric.

weights of the *same* body, at the same temperature, consame quantities of caloric. But equal weights of *different* ıt the same temperature, contain unequal quantities of ca- The quantity of caloric which one body contains, compar- that contained in another, has been considered by Dr. Irvine and others to be proportional to their *specific heats*, a term employed, by him and by others, to denote the quantity of caloric which a body requires, in order to be heated a single degree, or through a certain number of degrees, relatively to that required by any other body to produce the same change. The method of determining the *specific heat or specific caloric* of different bodies is as follows:

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[*] 82 Ann. de Chim. 34.

It has already been observed, that equal weights of the *same* body, at different temperatures, give, on admixture, the arithmetical mean. Thus, the temperature of a pint of hot water and a pint of cold, is, after mixture, very nearly half way between that of the two extremes. But this is not the case when equal quantities of *different* bodies, at different temperatures, are employed.

(*a*) If a pint of quicksilver, at 100° Fahrenheit, be mixed with a pint of water at 40°, the resulting temperature will not be 70° (the arithmetical mean), but only 60°. Here the quicksilver loses 40° of heat, which nevertheless raise the temperature of the water only 20°: in other words, a larger quantity of caloric is required to raise the temperature of a pint of water than that of a pint of mercury, through the same number of degrees. Hence it is inferred, that water has a greater capacity for caloric than is inherent in quicksilver.

(*b*) The experiment may be reversed by heating the water to a greater degree than the quicksilver. If the water be at 100°, and the mercury at 40°, the resulting temperature will be nearly 80°; because the pint of hot water contains more caloric than is necessary to raise the quicksilver to the arithmetical mean.

(*c*) Lastly, if we take two measures of quicksilver to one of water, it is of no consequence which is the hotter; for the resulting temperature is always the mean between the two extremes; for example, 70°, if the extremes be 100° and 40°. Here, it is manifest, that the same quantity of caloric, which makes one measure of water warmer by 30°, is sufficient for making two measures of quicksilver warmer by the same number. Quicksilver has, therefore, a less capacity than water for caloric, in the proportion, when equal measures are taken, of one to two.

If, instead of equal *bulks* of quicksilver and water, we had taken equal *weights*, the disparity between the specific caloric of the mercury and water would have been still greater. Thus a pound of water at 100° mixed with a pound of mercury at 40°, gives a temperature of 97½°, or 27½° above the arithmetical mean. In this experiment, the water, being cooled from 100° to 97½°, has lost a quantity of caloric, reducing its temperature only 2½°; but this caloric, communicated to the pound of mercury, has occasioned, in its temperature, a rise of no less than 57½°. Therefore, a quantity of caloric, necessary to raise the temperature of a pound of water 2½°, is sufficient to raise that of a pound of mercury 57½°; or, by the rule of proportion, the caloric, which raises the temperature of a pound of water 1°, will raise that of a pound of quicksilver about 23°. Hence it is inferred, that the quantity of caloric contained in water is to that contained in the same *weight* of quicksilver as 23° to 1°. Or, stating the caloric of water at 1°, that of quicksilver will be $\frac{1}{23}$ part of 1°, or 0.0435.[*]

In a similar manner may the specific heats of other bodies be ascertained. If a pound of water at 100°, and the same weight of oil at 50°, be mixed, the resulting temperature is not 75°, (the mean) but 83⅓°; the water, therefore, has lost only 16⅔°, while the oil has gained 33⅓°. Or, if equal weights of water at 50°, and oil at 100°, be mixed, the resulting temperature is 66⅔°, so that the oil has given out 33⅓°, and the water has increased only 16⅔°. (Dr. Thomson's Chemistry, vol. i.) Hence the heat, which raises a given weight of water 1°, will raise the same weight of oil 2°; and, as the specific heats are inversely as the changes of temperature, the specific heat of water may be called 1, and that of oil 0.5.

In some instances, it is not possible intimately to mix together the bodies under examination. When the specific heat of a solid mass of metal is to be ascertained, it may be heated throughout to a certain degree, and then surrounded by water of 32°, observing the increase of temperature which is gained by the water, and calculating the specific heat in the same manner as before. This was the method of Wilcke; but Lavoisier and Laplace substituted ice for water, placing, by means of an apparatus called the *Calorimeter*, the heated body in the centre of a quantity of ice, and determining the caloric evolved, by the quantity of ice melted in each instance.

When this comparison is extended to a great variety of bodies, they will be found to differ very considerably in their capacities for caloric. The results of numerous experiments of this kind are comprised in a table of specific caloric.[†]

The capacities of bodies for caloric, influence, considerably, the rate at which they are heated and cooled. In general, those bodies are most slowly heated, and cool most slowly, which have the greatest capacities for heat.[‡] Thus, if water and quicksilver be set in similar quantities, and at equal distances before the fire, the quicksilver will be much more rapidly heated than the water; and, on removal from the fire, it will cool with proportionally greater quickness than the water. By ascertaining then the comparative rates of cooling, we may determine, with tolerable exactness, the specific caloric of bodies.

It has been doubted whether the specific heats of bodies are permanent so long as they retain their form; in other words, whether a quantity of heat, which raises a body through a certain number of degrees at any one temperature, will raise it through an equal number of degrees at other temperatures. This subject, to which Mr. Dalton had formerly turned his attention,[§] has been lately investigated more completely by Petit and Dulong.[‖] They heated the body to be tried to the required temperatures, and ascertained what number of degrees of heat it communicated to a certain quantity of water. Repeating these trials at various points of the thermometric scale, they found that the specific heats of bodies are greater at high than at low temperatures. Thus the specific heat of iron was found to be as follows:

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[*] The above numbers, which differ from those commonly stated, are given on the authority of Mr. Dalton.

[†] See the Appendix.

[‡] See Martine on Heat, p. 74.

[§] New System, i. 53.

[‖] Ann. Philos. xiii.

Centigrade.	Specific heat.
From 0 to 100°	0.1098
0 to 200°	0.1150
0 to 300°	0.1218
0 to 350°	0.1255

The same law was found to extend to various other bodies, as is shown by the following Table:

	Sp. heats between 0° and 100° cent.	Sp. heats between 0° and 300° cent.
Mercury	0.0330	0.0350
Zinc	0.0927	0.1015
Antimony	0.0507	0.0549
Silver	0.0557	0.0611
Copper	0.0949	0.1013
Platinum	0.0355	0.0355
Glass	0.1770	0.1900

Another law, deduced by Petit and Dulong, from their researches on heat, is, that *the atoms of all simple bodies have precisely the same specific heat.* This, however, is to be considered, at present, merely in the light of an ingenious speculation, derived from a train of reasoning, a defect in any part of which must be fatal to the conclusions. (See Dalton's Strictures, in his New System, vol. ii. p. 280.) In the following Table, the specific heats of certain metals, found by their method, is given, together with the weights of the atoms of those metals, and the products of the specific heats and weights of atoms.

	Sp. heats, that of water being 1.	Weight of the atoms, that of oxyg. being 1.	Product of the weight of the atom by the sp. heat.
Bismuth	0.0288	13.300	0.3830
Lead	0.0293	12.950	0.3794
Gold	0.0298	12.430	0.3704
Platinum	0.0314	11.160	0.3740
Tin	0.0514	7.350	0.3779
Silver	0.0557	6.750	0.3759
Zinc	0.0927	4.030	0.3736
Tellurium	0.0912	4.030	0.3675
Copper	0.0949	3.957	0.3755
Nickel	0.1035	3.690	0.3819
Iron	0.1100	3.392	0.3731
Cobalt	0.1498	2.460	0.3685
Sulphur	0.1188	2.011	0.3780

Specific Heat of Gases.

The determination of the specific heat of gases is a difficult and important problem, which has successively employed the labour and ingenuity of Crawford, Lavoisier and De la Place, Leslie, Gay Lussac, Dalton, Delaroche and Berard, Clement and Desormes, Delarive and Marcet, and others.

Crawford began the investigation, and, after many unsuccessful attempts, adopted the following method. He procured two copper vessels, made extremely thin, and of the same size, shape, and weight. He filled one of these vessels with the gas under examination, previously deprived of moisture, and exhausted the other vessel by an air pump. He next heated both vessels by plunging them into boiling water, and then suddenly immersed both in cylinders containing a quantity of cold water, the same in each, just sufficient to cover them. The vessel, containing air or any gas, raised the temperature of the water surrounding it higher than the exhausted vessel; and, subtracting the latter increase from the former, he considered the remainder as the effect produced by the included gas, and as indicating its specific heat. The results were exhibited in a table, which it is unnecessary to insert, as they are now considered to be very remote from the truth, owing to the defects of the method of research employed by that ingenious philosopher.

Lavoisier and Laplace, pursuing the same inquiry, in a different way, used their calorimeter, through which they passed a current of gas, by means of a serpentine tube, enveloped by ice. The gas was heated by passing it through another serpentine, surrounded by boiling water, before it entered the calorimeter. A thermometer, placed at each end of the serpentine of the calorimeter, measured the temperature of the gas, when it entered and when it came out of the instrument. This mode of experimenting is, however, scarcely less objectionable than that of Crawford; and the calorimeter itself has been since proved to be liable to objections, as a measurer of heat, which prevent the results, obtained by its means, from being considered as more than loose approximations.

Mr. Leslie attempted the solution of the problem by a method founded on the following principle. If into a large glass receiver, from which the atmospheric air has been partly exhausted, any gas be allowed to enter, the dilated air, which the receiver contains, will be condensed; and its temperature will be increased by a constant quantity, whatever may be the entering gas. But the gas which is admitted will absorb a part of this excess of heat, and the mixture will have a mean temperature between that of the entering gas, and that which it would have acquired, if it had not been obliged to part with a portion of its heat. Now it is evident that this mean temperature will be so much the lower, the greater the specific heat of the gas which enters. From experiments made in this way, the inference seemed to follow, that equal volumes of hydrogen and atmospheric air have the same specific heat. Analogous experiments, however, made by Gay Lussac, gave different results. [illegible] therefore, to another. [illegible] of proceeding. It consisted in passing to the centre of a [illegible] reservoir, where a thermometer was placed, currents of two [illegible] gases, the one hot, the other cold. Knowing the temperature of the two gases before their mixture, and also that of the mixture, it was easy to infer the ratio of their specific heats. The numbers thus obtained do not differ very materially from those of Delaroche and Berard.

To the last mentioned philosophers we are indebted for the joint production of an elaborate memoir, containing the results of a set of experiments made with great patience and sagacity. To their essay (published in the 85th volume of the Ann. de Chim. and in the 2d vol. of Thomson's Annals, 1813) is prefixed an excellent account of all that had been previously done on the same subject. They employed a calorimeter; but, instead of using ice, they surrounded the serpentine tube, five feet in length, with water of a given temperature, and passed through it a known quantity of gas of a given temperature (212°) in an uniform current. The quantity of water, and the capacity of the containing vessel for heat, were previously determined; and the apparatus had the necessary appendages for ascertaining, at any moment, the quantity of heated gas, passed through the calorimeter, as well as the temperature of the water. In this way each gas might be expected to impart heat to the water, in greater or less quantity, compared with other gases, and in proportion to its capacity. The following Table exhibits the results of their experiments:

TABLE OF THE SPECIFIC HEATS OF SOME GASES.

NAMES OF GASES.	Under equal volumes.	Under equal weights.	Specific gravities.
Atmospheric air - - - -	1.0000	1.0000	1.0000
Hydrogen gas - - - - -	0.9033	12.340	0.0732
Oxygen gas - - - - -	0.9765	0.8848	1.1036
Nitrogen gas - - - - -	1.0000	1.0318	0.9691
Nitrous oxide - - - - -	1.3503	0.8878	1.5209
Olefiant gas - - - - -	1.5530	1.5763	0.9885
Carbonic oxide - - - -	1.0340	1.0805	0.9569
Carbonic acid - - - - -	1.2583	0.8280	1.5196

Taking water as unity, the specific heats of the gases are as follow:

Table of the Specific Heats of the Gases, water being taken as unity.

Water - - - - - -	1.0000	Azote - - - - - - -	0.2754
Atmospheric air - -	0.2669	Protoxide of azote -	0.2369
Hydrogen gas - - -	3.2936	Olefiant gas - - - -	0.4207
Carbonic acid - - -	0.2210	Oxide of carbon - -	0.2884
Oxygen - - - - - -	0.2361	Steam of water - -	0.8470

To the results of Delaroche and Berard it has been objected by Mr. Haycraft (Ann. de Chim. et Phys. xxvi. 298,) that they are too dependent on calculations and corrections, and that they were, in all cases, made on gases charged with moisture at an elevated temperature. He was, therefore, induced to contrive an apparatus, and to execute a set of experiments, in which these sources of fallacy should be avoided. By these he was led to conclude that all gases, simple as well as compound, have the same capacities for heat. This view, so far as respects simple gases, had already been taken by Petit and Dulong, from reasoning founded on the facts of Delaroche and Berard; but they do not appear to have thought of extending the laws to the compound gases.

The latest attempt to ascertain the specific heat of the gases is that of MM. Aug. de la Rive and F. Marcet, published in the Ann. de Ch. et de Phys. xxxv. 5. Admitting fully the merits of the researches of Delaroche and Berard, they are still of opinion that a few sources of fallacy were not provided against by those philosophers, which are sufficient to disturb the accuracy of their results. MM. Marcet and De la Rive undertook, therefore, a new set of experiments, and extended them to fourteen different gases, all prepared with the utmost attention, and carefully deprived of hygrometric moisture. The principle of their method was, to expose equal volumes of different gases to an uniform source of heat, during the same interval of time, the volume of gas being kept uniformly the same during the experiment. By the augmentation of elastic force in each gas, they judged of the temperature which it possessed at the end of the fixed period. This was easily deduced, by means of the law which connects the elastic force with the temperature of gases. It was found that all the gases were brought to the same temperature in the same interval, proving that they have all the same specific heat, with the single exception of hydrogen gas. This gas was heated $\frac{1}{10}$ of a centrigrade degree higher, than other gases under the same circumstances; not, however, the authors apprehend, from any difference of capacity, but because, being a much better conductor than any of the rest, it is more quickly heated and cooled. From a review of their experiments, they consider, then, the following conclusions as legitimately deducible.

1. That under the same pressure, and with equal and constant volumes (the elasticity alone varying,) all gases have the same specific heat.

2. That, all other circumstances remaining the same, the specific heat diminishes at the same time as the pressure, and equally for all the gases, according to a progression but little convergent, and in a much less ratio than that of the pressures.

3. That each gas has a different power of conducting heat.

Such have been the principal attempts to ascertain the specific heat of different gases, attempts which may be considered as having led to no decisive results, partly from the extreme nicety and delicacy of the necessary manipulations, and partly, perhaps, from some defect in the principle of the several investigations. In cases where the quantity of matter submitted to experiment is so exceedingly minute; where the changes of temperature are so small and evanescent; and, where so many causes operate, which it is difficult to separate from each other, it is not surprising that the most sagacious philosophers should have failed to arrive at sound, or even similar, conclusions. The subject then may be considered as still open to further research, and will well reward whatever skill and labour may be bestowed upon it.

After having investigated the specific heats of the different gases, MM. de la Roche and Berard ascertained that the specific heat of any one gas, considered with respect to its volume, augments with its density, but in a proportion less than the increase of density. On this subject MM. Clement and Desormes have given the following results:—

	Under pressure of in. of merc.	Specific heat.		Under pressure of in. of merc.	Specific heat.
Atmospheric air	39.6	1.215	Azotic gas - -	29.84	1.000
Ditto - - - - -	29.84	1.000	Oxygen - - -	29.84	1.000
Ditto - - - - -	14.92	0.693	Hydrogen - -	29.84	0.664
Ditto - - - - -	7.44	0.540	Carbonic acid -	29.84	1.500
Ditto - - - - -	3.74	0.368			

CHAPTER IV.

OF LIGHT.

The laws of light, so far as they relate to the phenomena of its movement, and to the sense of vision, constitute the science of Optics; and are the objects, therefore, not of Chemistry, but of Natural Philosophy. It may be proper, however, by a brief statement of its physical properties, to recall them to the memory of the reader.

1. The light of the sun moves with the velocity of 200,000 miles in a second of time, in consequence of which it passes through the whole distance between the sun and the earth in about eight minutes.

2. While it continues to move through a transparent medium of uniform density, its motion is in perfectly straight lines, but, in passing obliquely out of one medium into another, it undergoes a change of direction. If the new medium be denser than the old, the ray of light is bent or *refracted* nearer to the perpendicular; but, in passing out of a denser into a rarer medium, it is *refracted* from the perpendicular; and there is a constant proportion between the sine of the angle of incidence and that of refraction. Transparent media, also, not only cause a change of the direction of a ray, but

decompose it into its constituent parts, an effect which has been called *dispersion*.

3. In general the amount of refraction is proportional to the density of a body, but inflammable substances cause a greater refraction than might have been inferred from their densities, and the refractive power of the same inflammable substance bears a proportion to its perfection, insomuch that this property may be used as a test of its purity. Thus Dr. Wollaston found that genuine oil of cloves has a refractive power of 1.535, while that of an inferior quality did not exceed 1.498. The powers of the gases to refract light are exhibited in the following table of M. Dulong, drawn up from a series of recent experiments, conducted with the greatest care, and on gases of known purity. (Ann. de Ch. et de Phys. xxxi. 154.)

Table of the Refractive Powers of Gases, at the same Temperature and under the same Pressure, that of Air being taken as unity; by M. DULONG.

NAME OF GAS.	Refractive power.	Density.
Atmospheric air - - - - - - - - - -	1.	
Oxygen - - - - - - - - - - - -	0.924	1.1026
Hydrogen - - - - - - - - - - - -	0.470	0.0685
Azote - - - - - - - - - - - - -	1.020	0.976
Chlorine - - - - - - - - - - - -	2.623	2.47
Nitrous oxide - - - - - - - - - -	1.710	1.527
Nitrous gas - - - - - - - - - - -	1.03	1.039
Muriatic acid - - - - - - - - - -	1.527	1.254
Oxide of carbon - - - - - - - - -	1.157	0.972
Carbonic acid - - - - - - - - - -	1.526	1.524
Cyanogen - - - - - - - - - - - -	2.832	1.818
Olefiant gas - - - - - - - - - -	2.302	0.980
Carbureted hydrogen - - - - - -	1.504	0.559
Muriatic ether - - - - - - - - -	3.72	2.234
Hydrocyanic - - - - - - - - - - -	1.531	0.944
Ammonia - - - - - - - - - - - -	1.309	0.591
Oxi-chloro-carbonic - - - - - - -	3.936	3.442
Sulphureted hydrogen - - - - - -	2.187	1.178
Sulphurous acid - - - - - - - - -	2.260	2.247
Sulphuric ether - - - - - - - - -	5.197	2.580
Sulphuret of carbon - - - - - - -	5.110	2.644
Phosphureted hydrogen - - - - - -	2.682	1.256

4. When a ray of light arrives at the common surface of two media, and, instead of passing from the one into the other, is turned back into the first, this turning back is called *reflection*. The angles of incidence and reflection, are, in this case, always equal, whatever may be the obliquity of the incident ray.

5. All objects seen by reflection or refraction, appear in that

place or direction from whence the [illegible] ected or refracted to the eye.

6. There are certain bodies (Iceland spar for example) which exhibit a double image of any object that is viewed through them, or are said to *refract doubly*. In this case, one portion of the light is refracted according to the common law, the other undergoes an extraordinary refraction, in a plane parallel to the diagonal which joins the two obtuse angles of the crystal. If the ray, which has thus suffered double refraction, be made to fall on another crystal placed parallel to the first, no new division of the rays will happen; but if the second crystal be placed in a transverse direction, that part of the ray, which before suffered ordinary refraction, will now undergo extraordinary refraction; and that, which underwent extraordinary refraction, will now suffer ordinary refraction.

7. A ray of light, falling upon a polished surface of glass, [illegible] angle of 35° 25′, is reflected in a straight line at the same [illegible] But if a second plate of glass be so placed, that the reflected [illegible] will fall upon it likewise at an angle of 35° 25′, and if the second plate be slowly turned round its axis, without varying the angle which it makes with the ray that falls upon it, a curious phenomenon is observed. If the planes of reflection be parallel to each other, the ray of light is reflected from the second glass in the same manner as from the first. But if the second glass be turned round a quadrant of a circle, so as to make the planes of reflection perpendicular to each other, the whole of the ray will pass through the second glass, and none of it will be reflected. When the second glass is turned round another quadrant of a circle, so as to make the reflecting planes again parallel, the ray will be reflected by the second glass as at first; but when turned round three quadrants, the whole light will be again transmitted, and none of it reflected. Under certain circumstances, therefore, light can penetrate through glass when in one position, but not in another. In the latter case, it has been termed by Malus *polarized light*, on the supposition that the light has been bent into another position, as the needle is by a magnet.* For a popular statement of the discoveries of Malus, the reader is referred to the 33d vol. of Nicholson's Journal, p. 344; for those of Dr. Brewster, to the Phil. Trans. for 1813 and following years; and for the experiments of Biot and Arago, to the 94th vol. of Annales de Chimie, or to the Traité de Physique of the former philosopher.

Light is capable of producing also important chemical effects, and of entering into various chemical combinations. Its action is, for the most part, exerted in de-oxidizing bodies; and facts of this kind cannot be perfectly understood, until two important classes of bodies have been described, *viz.* those of oxides and of acids. In this place, therefore, I shall state only a few of its least complicated effects; and shall trace its agency on individual bodies, as they become the objects of experiment in the sequel.

1. Light, in the state in which it reaches the organ of vision, it

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* Thomson's Chemistry, i. 16.

is well known, is not a simple body, but is capable of being divided, by the prism, into seven primary rays or colours, *viz.* red, orange, yellow, green, blue, indigo, and violet. These are refrangible in the above order, the red being least refrangible, and the violet most so. The image formed by the different rays, thus separated, constitutes the SOLAR SPECTRUM. If it be divided into 300 parts, the red will occupy 45 of these parts, the orange 27, the yellow 48, the green 60, the indigo 40, and the violet 80. Dr. Wollaston found, however, that when a beam of light only $\frac{1}{20}$th of an inch broad, is received by the eye, at the distance of ten feet, through a clear prism of flint glass, only four colours are seen, *viz.* red, yellowish green, blue, and violet. The different coloured rays, being collected by a lens into a focus, again produce uncoloured light.

II. Heat and light are not present, in corresponding degrees, in different parts of the solar spectrum. With respect to the *illuminating* power of each colour, Dr. Herschell found that the red rays are far from having it in an eminent degree. The orange possess more of it than the red; and the yellow rays illuminate objects still more perfectly. The maximum of illumination lies in the brightest yellow or palest green. The green itself is nearly equally bright with the yellow; but from the full deep green the illuminating power decreases very sensibly. That of the blue is nearly on a par with that of the red; the indigo has much less than the blue, and the violet is very deficient.* In the Annals of Phil. N. S. iv. 157, a table of the illuminating powers of the prismatic rays is given by Frauenhofer, which is not copied in this place, because the colours of his spectrum do not correspond with those of Newton's.

III. The *heating* powers of the rays follow a different order. —If the bulb of a very sensible air thermometer be moved in succession, through the differently coloured rays, it will be found to indicate the greatest heat in the red rays; next in the green; and so on, in a diminishing progression, to the violet. The precise effects of the different rays, determined by Dr. Herschell's experiments, are as follows:

	The thermometer rose			
In the blue,	in 3	minutes from	55°	to 56°
—— green,	in 3	——	54	to 58
—— yellow,	in 3	——	56	to 62
—— full red,	in 2½	——	56	to 72
—— confines of red,	in 2½	——	58	to 73½

IV. When the thermometer is removed entirely out of the confines of the red rays, but with its ball still in the line of the spectrum, it rises even higher than in the red rays; and continues to rise, till removed half an inch beyond the extremity of the red rays. In this situation, quite out of the visible light, the thermometer rose in 2½ minutes from 61 to 79. The ball of the thermometer, employed for this purpose, should be and should be blackened with Indian ink. An air thermometer is better adapted than a mercurial one, to exhibit the minute change of temperature that ensues. These INVISIBLE HEAT-MAKING RAYS may be reflected by the mirror, and refracted by the lens, exactly in the same manner as the rays of light.

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* Phil. Trans. 1800, p. 267.

A fact has been ascertained by Dr. Delaroche, which seems to point out a close connexion between heat and light, and a gradual passage of the one into the other. At a temperature below that of boiling water, the rays of invisible heat pass through glass with difficulty, but they traverse it with a facility always increasing with the temperature, as it approaches the point when bodies become luminous. From these experiments it would appear that the modification, whatever it be, which must be impressed on the invisible rays, to render them capable of penetrating through glass, makes them approach more and more to the state in which they must be, when they enter the eye, and occasion the sensation of vision.

The experiments of Dr. Herschell, which had been already confirmed by Sir H. Englefield and other philosophers, were found correct in the main, when repeated by Mr. Berard,* who observed the same progressive heating power in the rays from the violet to the red. But he found the greatest heating power in the red extremity of the spectrum, and not beyond it. He fixed it at the point, where the bulb of the thermometer was still entirely covered by the red ray; and the thermometer sunk progressively, in proportion as the distance of its bulb from the red ray increased. Entirely out of the visible spectrum, where Herschell fixed the maximum of heat, its elevation above the ambient air was only one-fifth of what it had been in the red ray itself. The reflection of invisible radiant heat, Mr. Berard found, follows precisely the same law as that of light, and that the rays of heat are capable of polarization equally with those of light. Considerable differences in the results of experiments of this kind are, according to Dr. Seebeck, produced by the particular nature of the medium by which the rays of light are decomposed. (Ann. of Phil. N. S. viii. 235.) With a prism of fine flint glass, the greatest heat was always beyond the red rays; with a prism of crown glass, the greatest heat was in the red rays; and with a prism consisting of two hemispheres of glass inclosing water, the maximum of heat was in the yellow rays.

V. Beyond the confines of the spectrum on the other side, viz. a little beyond the violet ray, the thermometer is not affected; but in this place it is remarkable, that there are also invisible rays of a different kind, which exert all the chemical effects of the rays of light, and with even greater energy. One of the chemical properties of light, it will hereafter be stated, is, that it speedily changes, from white to black, the moist and fresh-precipitated chloride of silver, the chloride seizing the hydrogen of the water, and the silver uniting with oxygen. This effect is produced most rapidly by the direct light of the sun; and the rays, as separated by the prism, have this property in various degrees. The blue rays, for example, effect a change of the muriate of silver in 15 seconds, which the red require 20 minutes to accomplish; and, generally speaking, the power diminishes as we recede from the violet extremity. But entirely out of the spectrum, and beyond the violet rays, the effect is still produced. Hence it appears, that the solar beams consist of three distinct kinds of rays; of those that excite heat, and promote oxidation; of illuminating rays; and of DE-OXIDIZING OR HYDROGENATING RAYS. It has lately, also, been asserted by Morrichini, that the violet rays have a magnetizing power, and are capable of reversing the poles of a needle already magnetic.* His experiments, attempted without success by Configliachi and by Berard, have been fully confirmed by Mrs. Somerville, who found that a sewing needle, by less than two hours' exposure to the violet rays during bright sunshine, acquired the property of attracting the south pole, and repelling the north pole, of a magnetic needle. The position of the needle, thus exposed, with respect to the plane of the magnetic meridian, made no difference in the result. Needles exposed to blue and green rays sometimes acquired magnetism, though less frequently and more slowly; but, when acquired, the magnetism seemed as strong as when imparted by the violet rays. The indigo rays succeeded almost as well as the violet. (Phil. Trans. 1826, p. 132.)†

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* Thomson's Annals, ii. 163.

A striking illustration of the different heating powers of the various kinds of rays is furnished by their effect on phosphorus. In the rays beyond the red extremity, phosphorus is heated, smokes, and emits white fumes; but these are presently suppressed, on exposing it to the de-oxidizing rays, which lie beyond the violet extremity. "I found," says Sir H. Davy, (El. of Chem. Phil. p. 211.) "that a mixture of chlorine and hydrogen acted more rapidly upon each other, combining without explosion, when exposed to the red rays, than when placed in the violet rays; but that solution of chlorine in water became solution of muriatic acid most rapidly, when placed in the most refrangible rays of the spectrum. Puce-coloured oxide of lead, when moistened, gradually gained a tint of red in the least refrangible rays; and at last became black, but was not affected in the most refrangible rays; and the same change was produced by exposing it to a current of hydrogen gas. The oxide of mercury, procured by a solution of potassa and calomel, exposed to the spectrum, was not changed in the most refrangible rays, but became red in the least refrangible ones, which must have depended on its absorbing oxygen. The violet rays produced, upon moistened red oxide of mercury, the same effects as hydrogen gas."

The experiments of Berard‡ confirm those of Ritter and Wollaston. To show the disproportion between the energies of the different rays, he concentrated, by means of a lens, all that part of the spectrum, which extends from the green to the extreme violet; and, by another lens, all that portion, which extends from the green to the extremity of the red. In the focus of this last half, though intensely bright to the eyes, muriate of silver remained above two hours unaltered; but in that of the former half, though much less bright, it was blackened in less than six minutes.

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* Ann. de Chim. et Phys. iii. 323.

† Jour. of Science, v. 138; and Thomson's Annals, xii. 1.

‡ Thomson's Annals, ii. 165, and xvi. 6; also Brewster's Ed. Journal, i. 239; and Silliman's American Journal, i. 89.

VI. There is an exception, however, as stated by Dr. Wollaston, to the de-oxidizing power of the rays above mentioned. The substance, termed gum-guaiacum, has the property, when exposed to the light, of being changed from a yellowish colour to green; and this effect he has ascertained to be connected with the absorption of oxygen. Now, in the most refrangible rays, which would fall beyond the violet extremity, he found that this substance became green, and was again changed to yellow by the least refrangible.

VII. Certain bodies have the property of absorbing the rays of light in their totality; of retaining them for some time; and of again evolving them unchanged, and unaccompanied by sensible heat. Thus, in an experiment of Du Fay, a diamond exposed to the sun, and immediately covered with black wax, shone in the dark, on removing the wax, at the expiration of several months. Bodies, gifted with this property, are called SOLAR PHOSPHORI. Such are Canton's, Baldwin's, Homberg's, and the Bolognian phosphori, which will be described hereafter. To the same class belong several natural bodies, which retain light, and give it out unchanged. Thus snow is a natural solar phosphorus. So also is, occasionally, the sea when agitated; putrid fish have a similar property; and the glow-worm belongs to the same class. These phenomena are independent of every thing like combustion; for artificial phosphori, after exposure to the sun's rays, shine in the dark, or when placed in the vacuum of an air-pump, or under water, &c. where no air is present to support combustion.

VIII. From solar phosphori, the extrication of light is facilitated by the application of an elevated temperature; and, after having ceased to shine at the ordinary temperature, they again emit light when exposed to an increased one. Several bodies, which do not otherwise give out light, evolve it, or become phosphorescent, when heated. Thus, powdered fluate of lime becomes luminous, when thrown on an iron plate raised to a temperature rather above that of boiling water; and one of its varieties, known to mineralogists under the name of *chlorophane*, gives out abundantly an emerald green light by the mere heat of the hand; and after being exposed to the sun, or even to a candle, continues to shine in a dark place for some time. (Thomson's Annals, ix. 17. See also Quart. Journ. 2d Series, i. 232.) The yolk of an egg, when dried, becomes luminous, on being heated; and so also does tallow during liquefaction. To exhibit the last mentioned fact, it is merely necessary to place a lump of tallow on a coal, heated below ignition, making the experiment in a dark room.

IX. Attrition, also, evolves light. Thus, two pieces of common bonnet cane, rubbed strongly against each other in the dark, emit a faint light. Two pieces of borax or of quartz have the same property much more remarkably.

X. Light is disengaged in various cases of chemical combination. Whenever combustion is a part of the phenomena, this is well known to happen; but light is evolved, also, in other instances, where nothing like combustion goes forward. Thus, fresh prepared pure magnesia, added suddenly to highly concentrated sulphuric acid, exhibits a red light. When the vapour arising from a solid, benzoic acid for instance, is condensed, light is evolved, and also from fused boracic acid when passing to a solid form. But perhaps the most intense artificial light is that which is obtained by directing the flame of alcohol, by a stream of oxygen gas, upon a small spherule of lime about one quarter of an inch diameter. The lime from chalk is best adapted to this purpose, as it is most easy to give it the proper form. The light, thus produced, is so brilliant as scarcely to be borne by the naked eye, and its use is therefore suggested for illuminating light houses. It acts, also, as solar light does, on mixtures of chlorine and hydrogen, and on chloride of silver. (Lieut. Drummond. Phil. Trans. 1826, p. 324.)

XI. For measuring the relative intensities of light from various sources, an instrument has been contrived, called the PHOTOMETER. That of Count Rumford, described in the 84th volume of the Philosophical Transactions, being founded on optical principles, does not fall strictly within the province of this work. It is constructed on the principle, that the power of a burning body, to illuminate any defined space, is directly as the intensity of the light, and inversely as the square of the distance. If two unequal lights shine on the same surface at equal obliquities, and an opaque body be interposed between each of them and the illuminated surface, the two shadows must differ in intensity or blackness; for the shadow formed by intercepting the greater light will be illuminated by the lesser light only; and, reversely, the other shadow will be illuminated by the greater light; that is, the stronger light will be attended with the deeper shadow. But it is easy, by removing the stronger light to a greater distance, to render the shadow, which it produces, not deeper than that of the smaller, or of precisely the same intensity. This equalization being effected, the quantity of light emitted by each lamp or candle, will be as the square of the distance of the burning body from the white surface.

The photometer of Mr. Leslie is founded on a different principle, *viz.* that light, in proportion to its absorption, produces heat. The degree of heat produced, and consequently of light absorbed, is measured by the expansion of a confined portion of air. A minute description of the ingenious instrument contrived by Mr. Leslie with this view, may be seen in his work on Heat, or in the 3d vol. of Nicholson's 4to. Journal. In its construction, it bears a considerable resemblance to the differential thermometer, already described, and represented plate i. fig. 7. As both the balls of the latter instrument, however, are transparent, no change ensues in the situation of the coloured liquid when it is exposed to the variations of light. But, in the photometer, one of the balls is rendered opaque, either by tinging the glass, or by covering it with a pigment; and hence this ball, absorbing the incident light which passes freely through the transparent one, the air, included in it, becomes warmer than that of the other ball, and, by its great elasticity, forces the liquid up the opposite leg of the instrument. A graduated scale measures the amount of the effect; and a glass covering defends the photometer from being influenced by the temperature of the atmosphere.

Mr. Brande has ascertained that by substituting ether, as in Dr. Howard's modification of the differential thermometer, the sensibility of the photometer is greatly increased, and that it becomes most delicately susceptible of the impression of light. An instrument of this sort he found fully adequate to determine the comparative illuminating powers of different gases, which cannot be done when the photometer is filled with air. (Quart. Journ. viii. 220.) Those, who are desirous of more ample information on the subject of measuring light, may consult with advantage the Rev. Mr. Powel's Historical Sketch of Photometry in the second series of Ann. of Phil. xi. 371.

CHAPTER V.

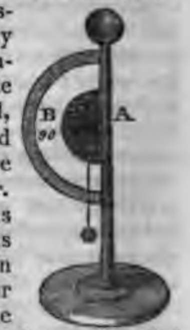
ON THE CHEMICAL AGENCIES OF ELECTRICITY.

The phenomena and laws of electricity as ordinarily excited, being more strictly the objects of natural philosophy than of chemistry, and forming a prominent part of almost every elementary treatise on the former branch of science, I consider it unnecessary in this place to say more than is sufficient to recall them to the memory of the reader, and to connect them with that modification of electricity, which, under the name of Galvanism, has proved so powerful an instrument of chemical research.

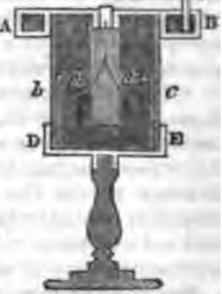
When a glass tube of sufficient diameter, perfectly clean and dry, is briskly rubbed with a dry silk handkerchief, and then brought near to small light bodies, such as bits of thin paper, straw, feathers, or gold leaf, these bodies fly to the glass, and adhere to it for some time. A gilt ball of light pith, suspended by a slender silken thread, is attracted by the tube, and, if the latter be near enough, first comes into contact with it, and is then repelled. These effects are much more strikingly produced by an *electrical machine*, which consists, essentially, of a circular glass plate or glass cylinder, fixed upon an axle, and pressed by a cushion or *rubber*, which is generally besmeared with a soft compound of an amalgam of mercury and tin mixed with grease. At a short distance, is placed a metallic cylinder, supported by glass feet, called the *prime conductor*, which, at the end next the glass, has commonly a few projecting teeth made of pointed wire. The rubber being connected by a small chain, or otherwise, with the table or floor, and the glass cylinder or plate made to revolve upon its axle, a crackling noise is heard, accompanied with a luminous appearance, and on bringing the knuckle of a finger, or a rounded metallic knob, near the prime conductor, a spark issues, accompanied with a snap or slight report, and with a pricking sensation when the knuckle is presented. In this case the glass is said to be *excited*, and the prime conductor to be *charged* with electricity.

If, while the prime conductor is thus charged, we bring two gilt pith balls, suspended by fine silken threads and in contact with each other, within a short distance of it, they immediately fly asunder, but when removed from its vicinity, the balls again collapse or fall together. Now both the balls, having been exposed to the same influence, may be considered as in the same electrical state; and hence *bodies similarly electrified are said to repel each other.* But let us next vary the circumstances of the experiment, and, instead of connecting the rubber with the ground, connect it with a second prime conductor, and let a wire be attached to each conductor, from which the balls may hang separately, each by its thread, and with a small intermediate space. The phenomena will now be very different. The balls instead of diverging will attract each other, and come into contact. *Bodies, therefore, differently electrified attract each other.* In the first case, the excited glass derives from the earth its electricity, which flows to the conductor, and is there accumulated. In the latter case, the second conductor supplies electricity through the means of the rubber to the first, and all that happens is the disturbance of the electrical state of the two conductors, the first gaining precisely what the second has lost. The electricity of the first is said to be *plus* or *positive*, and that of the second *minus* or *negative*. This view of the subject accounts for the phenomena of electricity by supposing one fluid only, equally subtile with caloric and light, the redundance of which causes the state of *positive*, and its deficiency that of *negative* electricity. This is the theory of Franklin, supported by Æpinus, Cavendish, &c. But many philosophers, especially on the continent, adopt the theory of Dufay, that there are two distinct electric fluids, the *vitreous* corresponding to the positive, and the *resinous* to the negative; that these fluids are separated from each other by friction; and that their re-union is followed by the cessation of electrical phenomena. It must be acknowledged, that all the facts respecting electricity are explicable upon either of these hypotheses, but on the whole that of Franklin appears to me entitled to preference.

All bodies are not capable of being excited by friction. Among those which are so, the principal ones are, glass, sulphur, wax, resins, amber, precious stones, silk and cotton, feathers, hair, wool, &c. Such bodies are called *electrics;* and, as they do not afford a passage to the electric fluid, they are also called *non-conductors.* There is another class of bodies which readily transmit electricity, and are therefore called *conductors;* and as these cannot easily and without particular management be excited by friction, they are also called *non-electrics.* A body of the latter class, supported by a non-conductor (a metallic cylinder, for instance,) resting on glass feet, is said to be *insulated.* In this state, the insulated body will retain a charge of electricity for some time, because the air of the atmosphere, when of its ordinary dryness and density, is a slow or bad conductor of electricity.

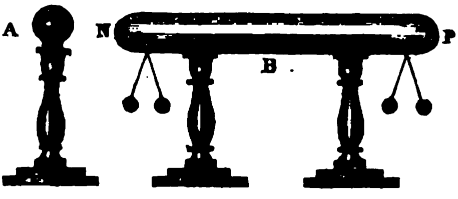


The more highly an insulated conductor is charged with electricity, the more powerful is the repulsion which it communicates to bodies that are brought near it. Two pith balls for instance, suspended from a prime conductor, diverge to a distance proportional to the accumulation of electricity in the conductor; or a single pith ball may be employed, as in the *quadrant electrometer*, shown in the annexed figure. A is a round upright rod of metal, with a ball at the top, and pointed at the lower end so that, when separated from its stand, it may be received into a small hole in the prime conductor. B is an ivory semicircle, the lower half of which is graduated into 90 equal parts: to the centre of this a pin is fixed horizontally, upon which a very thin piece of cane or ivory, having a pith ball at its lower extremity, turns freely, and traverses the circle like an index. When no electricity is excited, the cane hangs parallel to the stem; but on turning the machine, the ball rises and carries the index over the circle, to a point which indicates the degree of electric excitement. What is measured, however, by this instrument, is not so much the *quantity* of electricity, as its *tension* or *intensity*, terms perhaps not very remote in their meaning from what is expressed by *elasticity* as belonging to aëriform fluids. It must be obvious that the gravity of the pith ball will be opposed to its being moved by very slight electrical powers. To obviate this, a very ingenious instrument was contrived by Coulomb, called the *balance of torsion*, described in most elementary works on natural philosophy.



To discover very minute deviations from the electric equilibrium, and to discriminate between positive and negative electricity, Mr. Bennett employed two slips of gold leaf *m*, *n*, enclosed in a cylindrical vessel of glass, *b*, *c*, closed at the bottom with a metallic cap D E, and with a similar one, A B, at the top; the inferior surface of the upper cap, as well as the top part of the inside of the cylinder, being coated with sealing-wax. From the centre of the upper cap the two slips of gold leaf hang vertically, and are opposed to two slips of tin-foil, pasted to the inside of the cylinder, [illegible] *b*, *c*, and so placed that the gold leaves may come in contact with them, when their mutual repulsion is made powerful enough to separate them to that extent. These slips of tin-foil terminate in the foot of the instrument, and therefore communicate with the earth. On touching the upper cap, or the pin C, with an electrified body, the gold leaves diverge. If the divergence be increased by the approach of flint glass excited by silk, the electricity is said to be positive; if the divergence be diminished, they are said to be negatively electrified.

Beside friction, electricity is also developed by the fusion and solidification of bodies. If, for instance, melted sulphur be poured into an insulated metallic cup, when the sulphur has congealed, the sulphur and the cup are found to be in opposite electrical states. Electricity is also excited by evaporation, as may be seen, if, into a small metallic cup of water, placed on the top of Bennett's gold leaf electroscope, we drop a hot cinder; for the gold leaves instantly diverge. The condensation of vapour also produces electrical appearances, and is probably the cause of many of those phenomena which arise from different states of the atmosphere.



But, independently both of friction and heat, there is yet another way in which electricity is called into action, *viz.* by the mere contiguity of an electrified body. Let B be an insulated conductor, and let it be placed in the vicinity of A, an electric, excited, we will suppose, positively; it will be found by the test already described, that the end of B next to A is excited negatively, and the remote end of B positively. Reversing the experiment, and making A negative, the nearest end of the conductor will be positive, and the remote negative; and the middle of the conductor will be neutral. If the electric, A, be removed from the vicinity of B, and its electricity examined by the quadrant electrometer, it will be found to be precisely the same as before approaching it to B, and the signs of opposite electricities in B, consisting in the divergence of the two pairs of balls, will have ceased. In this case, all that happens to B is a disturbance of the equilibrium of its electricity, occasioned, it should appear, by the repulsive action of the electric atmosphere of A, and ceasing on its removal. To electricity, thus set in motion by mere contiguity, the French philosophers have given the name of *electricité par influence*, and in our own language it is called *electricity by induction*, or *induced electricity*. It is a law of considerable importance, and has been successfully applied to explain the phenomena of the Leyden jar, and of the instruments called electrical *doublers* and *condensers*. It would lead me too far from the subject to trace it through these applications. It may be sufficient to remind the reader, that when the inside of a Leyden jar is rendered positive by its communication with the charged conductor of a machine, the outside of the jar is, by the law of induction, rendered negative, in exactly the same degree. The restoration, through a conductor, of the equilibrium of electricity between the two surfaces, is attended with a snap or report. If we unite several jars together, by wires descending to the inner coating, and joined at the top, we greatly increase the loudness of the report, and the other effects of the charge. Such a combination of single jars constitutes the *electrical battery*.

All the phenomena of electricity, it appears, are proportional to the superficial extent of bodies, and not to their masses. Hence the prime conductor of a machine is always a hollow cylinder of metal. The excitation of electrics depends too materially upon the nature of their surface; and, by altering this, the kind of their electricity may even be reversed. Thus polished glass imparts positive electricity when rubbed with silk, but negative, if the surface of the glass be previously made rough by grinding.

We may now proceed to a modification of electricity exhibited by a series of phenomena, which have for their cause the subtile fluid, of whose laws a very general outline has been offered. Thus modified it has received the name of Galvanism.

That branch of natural science which comprehends the phenomena of GALVANISM, and the general principles under which they are arranged, is only of recent origin. It was not till the year 1791, that Galvani, an Italian philosopher, being engaged in a course of experiments on animal irritability, observed accidentally the contractions, which are excited in the limbs of frogs, by applying a conductor of electricity between a nerve and a muscle. The theory, which he framed to account for this phenomenon, was, that the different parts of an animal are in opposite states of electricity, and that the effect of the metal is merely to restore the equilibrium. The analogy, however, was afterwards shown to be without foundation. For Volta excited similar contractions, by making a connexion between two parts of a nerve, between two muscles, or between two parts of the same muscle; but, to produce the effect, two different metals were found to be essential. Hence he was led to infer that, by the contact of different metals, a small quantity of electricity is excited; and to the agency of this electricity, first upon the nerves, and through their mediation on the muscles, he ascribed the phenomena in question.

Several years elapsed, during which the action of galvanic electricity on the animal body, and the discussion of its cause, occupied chiefly the attention of philosophers. Early in 1800, the subject took a new turn, in consequence of the discovery by Signor Volta of the Galvanic pile;* a discovery which has furnished us with new and most powerful instruments of analysis. From this period, discoveries have multiplied with a rapidity, and to an extent, which surpass any thing before known in the history of science; and the facts are now become so numerous, that an arrangement and classification of them seem to be preferable to an historical detail in the order of time. The method, which appears to me best calculated to give a distinct view of the subject, is to describe,

I. The construction of galvanic apparatus, and the circumstances essential to the excitement of this modification of electricity:

II. The facts, which establish its identity with the electricity excited by ordinary processes:

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* Philosophical Transactions, 1800; or Philosophical Magazine, vii. 287.

III. The agency of the electric or galvanic fluid in producing chemical changes:

IV. The theory, by which these changes, in the present state of our knowledge, are best explained:

V. The hypotheses, which have been framed to account for the origin of the electricity, excited by galvanic arrangements: And,

VI. I shall offer a very general view of the phenomena of electro-magnetic motion, which, with the principles deducible from them, promise to throw light on some of the most interesting, but obscure, operations of nature.

SECTION I.

Of the construction of Galvanic Arrangements.

The conditions, required for the excitement of galvanic electricity, are altogether different from those which have been described as essential to the excitation of the electric fluid by long known methods, for the class of bodies, termed electrics, have not necessarily any share in the phenomena. All that is required is the simple contact of different *conducting bodies* with each other. Conductors of electricity have been divided into *perfect* and *imperfect*, the former comprehending the metals, plumbago and charcoal, the mineral acids, and saline solutions; the latter, or imperfect, including water, alcohol and ether, sulphur, oils, resins, metallic oxides, and compounds of chlorine.

The least complicated galvanic arrangement is termed A SIMPLE GALVANIC CIRCLE. It consists of three conductors, of which one at least must be solid, the second fluid, the third may be either solid or fluid. In the following Tables, constructed by Sir H. Davy, some different simple circles are arranged in the order of their powers, the most energetic occupying the highest place.

Table of some Electrical Arrangements, which, by combination, form Voltaic Batteries, composed of two perfect Conductors and one imperfect Conductor.

Zinc, Iron, Tin, Lead, Copper, Silver, Gold, Platinum, Charcoal,	Each of these is the positive pole to all the metals below it, and negative with respect to the metals above it in the column.	Solutions of nitric acid, of muriatic acid, of sulphuric acid, of sal ammoniac, of nitre, of other neutral salts.

Table of some Electrical Arrangements, consisting of one perfect Conductor and two imperfect Conductors.

Solution of sulphuret of potassa, of potassa, of soda,	Copper, Silver, Lead, Tin, Zinc, Other Metals, Charcoal.	Nitric acid, Sulphuric acid, Muriatic acid, Any solutions containing acids.

In explanation of these Tables, Sir H. Davy observes, that in all cases when the fluid menstrua afford oxygen, those metals, which have the strongest attraction for oxygen, are those which form the positive pole. But when the fluid menstrua afford sulphur to the metals, the metal which, under the existing circumstances, has the strongest attraction for sulphur, determines the positive pole. Thus, in a series of copper and iron plates, introduced into a porcelain trough, the cells of which are filled with water, or with acid solutions, the iron is positive and the copper negative; but when the cells are filled with solution of sulphuret of potassa, the copper is positive and the iron negative. When one metal only is concerned, the surface opposite the acid is negative, and that in contact with solution of alkali and sulphur, or of alkali, is positive. (El. of Ch. Phil. p. 148.)

Several attempts have been made to form galvanic circles without metals; but though successful to a certain degree, they have but feeble powers. Of this kind are alternate layers of charcoal and plumbago; layers of muscle and brain, with pieces of moistened cloth or leather interposed;—and discs of red beet-root, two inches in diameter, with discs of walnut tree of the same size, divested of their resin by digestion in a solution of cream of tartar in vinegar. With the last, galvanic effects were produced on a frog, a leaf of scurvy grass being taken as an exciter. (Nich. Jour. xviii. 159.)

The powers of simple galvanic circles are but feeble; but they may be made sufficiently apparent by the following experiments.

1. When a piece of zinc is laid upon the tongue, and a piece of silver under it, no sensation is excited, so long as the metals are kept apart; but, on bringing them into contact, a metallic taste is distinctly perceived. In this case we have an example of the arrangement of two perfect conductors (the metals) with one imperfect one (the tongue, or rather the fluids which it contains). The metallic taste arises, in all probability, from the excitement of a small quantity of electricity by the contact of the metals, and its action on the nerves of the tongue.

2. A piece of zinc, immersed under water which is freely exposed to the atmosphere, oxidizes very slowly; but when placed in the same situation, in contact with a piece of silver, its oxidation is much more rapid. By immersing iron and silver (also in

contact with each other) under diluted muriatic acid, the action of the acid upon the iron is considerably increased; and hydrogen gas is evolved from the water, not only where it is in contact with the iron, but where it touches the silver. These facts explain, why, in the sheathing of ships, it is necessary to use bolts of the same metal which forms the plates; for if two different metals be employed, they both oxidate, or rust, very speedily, in consequence of their forming, with the water of the ocean, a simple galvanic circle.

Of compound Galvanic Circles or Batteries.

Galvanic batteries are formed by multiplying those arrangements, which compose simple circles. Thus if plates of zinc and of silver, and pieces of woollen cloth of the same size as the plates, and moistened with water, be piled upon each other (fig. 77. pl. ix.), in the order of zinc, silver, cloth; zinc, silver, cloth; and so on, for twenty or more repetitions, we obtain a galvanic battery; termed, from its discoverer, the *Pile of Volta.* The power of such a combination is sufficient to give a smart shock, as may be felt by grasping in the hands, which should be previously moistened, two metallic rods, and touching with these the upper and lower extremities of the pile. The shock may be renewed at pleasure; until, after a few hours, the activity of the pile begins to abate, and finally ceases altogether.

The metals composing a galvanic battery, may be more conveniently arranged in the form of a trough, a happy invention of Mr. Cruickshank. In a long and narrow wooden trough, made of baked wood, grooves are cut, opposite to and at the distance of between ½ and ¾ of an inch from each other; and into these are let down, and secured by cement, square plates of zinc and copper, previously united together by soldering. (See figs. 67 and 78.) The space, therefore, between each pair of plates forms a cell for the purpose of containing the liquid, by which the combination is to be made active. The advantage of this contrivance, over the pile, is partly that it is much more easily put in order; but, besides this, it is a more efficient instrument. When constructed in the way which has been described, it affords an example of a galvanic combination *of the first kind*, formed by two perfect and one imperfect conductor. But it admits of being modified, by cementing, into the grooves, plates of one metal only, and filling the cells, alternately, with two different liquids, as diluted nitric acid and solution of sulphuret of potash. In this case, we have a battery *of the second order*, formed by the repetition of one perfect and two imperfect conductors. For all purposes of experiment, the first kind of arrangement is universally preferred.

Another modification of the apparatus, which may be called the *Chain of Cups*, was proposed by Volta at the same time that he communicated his invention of the Pile; and, from the experiments of Mr. Children,* it appears to be a very useful and powerful one.

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* Philosophical Transactions, 1809, p. 32.

It consists of a row of glasses (see fig. 75), such as wine glasses or small tumblers, for the purpose of containing any fluid that may be selected. Into each of these glasses is plunged a plate of zinc and another of copper, each not less than an inch square, which are not to touch each other. The plates of different cups are connected by metallic wires or arcs, in such a manner that the zinc of the first cup communicates with the copper of the second; the zinc of the second with the copper of the third; and so on through the whole row. The shock is felt on dipping the fingers of one hand into the fluid of the first cup, and those of the other hand into the last of the series. The superiority of this arrangement consists in both surfaces of each metallic plate being exposed to the action of the liquid; whereas, by soldering the plates together, one of the surfaces of each is protected from the liquid, and contributes nothing to the effect. The common trough has lately been made to combine this advantage, by dividing it into cells, not by plates of metal, but by partitions of glass. Into each of these cells filled with the proper liquid, a plate of each metal is introduced, but not so as to touch each other. A communication is then made by a metallic arc, between the zinc plate of each cell and the copper one of the next, precisely as in the chain of cups. More lately the troughs themselves have been made of earthen ware, and the partitions of the same material; the apparatus being completed, in other respects, in the manner already described. The plates, also, are now so suspended, that when not in use, they may all be lifted out of the cells at once.* And it has been recently ascertained that the power of a battery is increased at least one half by placing in each cell one zinc and two copper plates, so that each surface of zinc may be opposed to a surface of copper.†

The size of the plates has been varied from one or two inches to several feet. The large battery, described by Mr. Children in the Philosophical Transactions for 1815, consisted of plates each six feet by two feet eight inches, equal to 32 square feet; and the cells were capable of containing about 945 gallons of liquid. For ordinary purposes, plates of two inches square are sufficient; but for the decomposition of several bodies, not less than 100 pairs of plates, each four inches square, are required.‡ The enlargement of the size of the troughs, so as to contain this number, would be extremely inconvenient; and we may therefore combine the power of several troughs, by uniting the zinc end of the one with the copper end of the other, by the intervention of a metallic wire, or by an arc of silver or zinc.

A convenient and powerful galvanic battery, called, from the nature of its effects, a *calorimotor*, has been constructed by Dr. Hare of Philadelphia, of zinc and copper sheets formed into coils. The zinc sheets were about nine inches by six; the copper fourteen by six; more of the latter metal being necessary, as, in every coil, it was made to commence within the zinc, and completely to surround it without. The sheets were coiled so as not to leave between them an interstice wider than a quarter of an inch. Each coil was, in diameter, about two inches and a half; their number amounted to 80; and, by means of a lever, they were made all to descend together into 80 glass jars, 2 inches and 3-4ths diameter inside, and eight inches high, duly placed to receive them. The effects of this apparatus, in producing ignition, appear to have been very striking, especially at the moment of immersion, when Dr. Hare found the effect to be by much the most powerful. (Silliman's Journal, iii. 105.) An apparatus of 80 coils produced a vivid ignition in charcoal; and when the points of the charcoal were drawn three-fourths of an inch apart from each other, a most brilliant arc of flame extended between them. The powerful apparatus, constructed under the direction of Mr. Pepys, for the London Institution, belongs also to this class. (Phil. Trans. 1823.)

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* See Pepys, in Journal of Science, &c. i. 193.

† Phil. Trans. 1815.

‡ Some useful information respecting the number and size of plates, adapted to different purposes, is given by Mr. Singer in Nicholson's Journal, xxiv. 174.

It may be sufficient to add, in general terms, that every combination, which is capable of forming a simple galvanic circle, may, by sufficient repetition, be made to compose a battery. The combinations, also, which are most active in simple circles, are observed to be most efficient in compound ones. The foregoing tables of Sir H. Davy express, therefore, the powers of compound as well as of simple arrangements.

To construct a battery *of the first order*, it is essential that a fluid be employed, which exerts a chemical action upon one of the metals. Pure water, entirely deprived of air, appears to be inefficient. In general, indeed, the galvanic effect is, within certain limits, proportional to the rapidity with which the more oxidable metal is acted upon by the intervening fluid. Spring water was found sufficient, in Mr. Children's immense battery, to produce the ignition of platinum wire. The fluid generally used is nitric acid, diluted with 20 or 30 times its weight of water. Mr. Children recommends a mixture of three parts fuming nitrous acid, and one sulphuric diluted with thirty parts of water. Directions, also, respecting the best kind and density of acids, for producing galvanic electricity, are given by Mr. Singer. From his experiments it appears, that acid of different densities is required for different purposes. The best wire-melting charge is formed with ten gallons of water, five pounds of nitric acid, and half a pound of muriatic acid.

The power of the apparatus has been found to be increased, when insulated by non-conductors; and when surrounded by an atmosphere of oxygen gas; not sufficiently, however, to make it necessary to resort to either of these expedients in ordinary cases. Oxygen gas disappears in this process, when carried on under a receiver; and, after all the oxygen is absorbed, the effect ceases, and is renewed by introducing a fresh portion. A battery, also, which has ceased to be efficient, has its activity renewed by emptying the cells of their liquor, and uncovering the plates. When these cells are filled with diluted nitric acid, the apparatus continues active, even under the exhausted receiver of an air-pump, or in an atmosphere of carbonic acid or nitrogen gases. But if the cells be filled with water only, all action is suspended, by placing it under any of these circumstances. Hence it appears that the oxidation of one or both of the metals, composing the trough, is essential to the excitement of galvanic electricity.

The *electric column* may be classed among galvanic arrangements. It was originally contrived by M. de Luc, who formed it of discs of Dutch gilt paper, alternated with similar discs of laminated zinc. These were piled on each other in a dry state (or at least in a state of dryness at ordinary temperatures, for paper cannot be made or preserved absolutely dry, except at a heat nearly sufficient to scorch it). This instrument, instead of being soon exhausted, like the pile with humid substances, was found to continue active for some years.* A similar pile may be formed by laying a mixture of very finely powdered zinc with common glue and a little sugar, by means of a brush, on the back of Dutch gilt paper; and, when dry, cutting it into discs, which are to be piled on each other.† Zamboni of Verona has constructed a pile of slips of silver paper, on the unsilvered side of which is spread a layer of black oxide of manganese and honey. These papers are piled on each other to the number of 2000; then covered externally with a coating of shell lac; and enclosed in a hollow brass cylinder. Two of these piles are placed at the distance of four or five inches from each other; and between them is suspended on a pivot a light metallic needle, which is attracted alternately to the one pile and the other, so that it moves between them like a pendulum. This instrument has been applied to the measurement of time, by causing it to give motion to the pendulum of a clock.‡

SECTION II.

On the mutual Relation of Electricity and Galvanism.

Is the influence, it may now be inquired, which is called into action in a way so different from that employed for the excitation of ordinary electricity, identical with it or of a different kind? This question will be decided by examining whether any of those phenomena, which are occasioned by the agency of the electric fluid, are produced also by that of galvanism; and we shall find the following striking resemblances:

1. The sensation produced by the galvanic shock, is extremely similar to that which is excited by the discharge of a Leyden jar. Both influences, also, are propagated through a number of persons, without any perceptible interval of time.

2. Those bodies, which are conductors of electricity, are also

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* Nicholson's Journal, vol. xxvi.

† Phil. Mag. xlvii. 265.

‡ Phil. Mag. xlv. 261. and Ann. de Ch. et de Phys. xi. 190.

conductors of the galvanic fluid, as the metals, charcoal, and a variety of liquids. Again, it is not transmitted by glass, sulphur, and the whole class of electrics, which do not convey ordinary electricity. Among liquids, those only are conductors of electricity and galvanism, which contain oxygen as one of their elements.*

3. The galvanic fluid passes through air and certain other non-conductors, in the form of sparks; accompanied with a snap or report; and, like the electric fluid, it may be made to inflame gunpowder, phosphorus, and mixtures of hydrogen and oxygen gases. It has been found, also, by Mr. Children, that in the Voltaic apparatus there is, what is called in electricity, *a striking distance.* With a power of 1250 pairs of four inch plates, he found this distance to be one 50th of an inch, the thickness of a plate of air, through which the galvanic discharge is able to pass in the form of a spark. Increasing the number of plates, the striking distance will be greater; and the reverse when it is diminished. It is also increased by rarefying the air, through which the spark is transmitted.

4. The Voltaic apparatus is capable of communicating a charge to a Leyden jar, or even to a battery. If the zinc end of a pile (whether it be uppermost or the contrary) be made to communicate for a moment with the inside of a jar, it is charged positively. If circumstances be reversed, and the copper end be similarly connected, the jar is charged negatively.† The shocks do not differ from those of a jar or battery, charged to the same intensity by a common electrical machine.

5. Galvanism, even when excited by a single galvanic circle only (such as a piece of zinc, a similar one of copper, and a piece of cloth moistened with a solution of muriate of ammonia), distinctly affects the gold leaf of the condensing electrometer. If the zinc end be uppermost, and be connected directly with the instrument, the electricity indicated is positive; if the pin of the electrometer touch the copper, the electricity is negative. A pile consisting of sixty combinations produces the effect still more remarkably.‡

6. The chemical changes produced by galvanic and common electricity, so far as they have hitherto been examined, are precisely similar. These will form the subject of the following section.

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* Cruickshank, in Nicholson's 4to. Journal, iv. 258.

† Cuthbertson's Practical Electricity and Galvanism, p. 261; Volta, in Nicholson's Journal, 8vo. i. 140; Van Marum, in Philosophical Magazine, xii. 162; Singer, p. 126.

‡ Nicholson, 4to. iv. 174, 8vo. i. 139, and ii. 281; Cuthbertson, p. 264; and Singer, p. 317; where the cautions necessary to the success of this delicate experiment are particularly described.

SECTION III.

On the Chemical Agencies of Electricity and Galvanism.

The effects of the electric or galvanic fluids, in producing chemical decomposition, cannot be described, without introducing to the reader the names of several substances, with which, in the present state of his knowledge, he may be supposed to be unacquainted. This difficulty is unavoidable; for it is impossible to explain the general laws of electro-chemical action, without a variety of particular instances. In general, however, it will be found that a minute acquaintance with the bodies, which are brought in illustration, is by no means essential; and that it is sufficient to consider them abstractedly as composed of two ingredients, which are in opposite electrical states, and are subject to the laws of electrical attraction and repulsion.

The most simple chemical effect, produced alike by the agency of electricity and galvanism, is the *ignition* and *fusion* of *metals*. When a piece of watch-pendulum wire is placed in the circuit of a common electrical battery, containing not less than three or four square feet of coating, at the moment of the discharge the wire becomes red-hot; but continues so only for a few seconds; no longer, indeed, than if it had been ignited in any other way.* The same effect may be produced by making a piece of wire the medium of communication between the opposite extremities of a galvanic trough; but, in this case, the heat continues sensibly longer, than when it is excited by an electrical explosion. Indeed, a platinum wire may be kept ignited *in vacuo*, for an unlimited time, by Voltaic electricity. Water, surrounding a wire so placed, may be made to boil briskly.

By means of his large battery, Mr. Children not only ignited wire of considerable thickness; but a bar of platinum, $\frac{1}{8}$th of an inch square and $2\frac{1}{4}$ inches long, was ignited, and even fused at one end. The facility of being ignited, in the different metals, appeared to be inversely proportional to their power of conducting heat. Thus platinum, which has the lowest conducting power, was most easily ignited; and silver, which conducts heat better than any other metal, was ignited with greater difficulty than any of the rest.

It does not appear, however, that a very powerful combination is required to produce ignition, if the wire be made of proportionately small diameter. Dr. Wollaston has ascertained that a wire $\frac{1}{3000}$ of an inch in diameter may be ignited by a single zinc plate only one inch square, provided each of its surfaces be opposed to a surface of copper or some other metal. The liquor, which he employed, was a mixture of one measure of sulphuric acid with 50 measures of water. Any farther diminution in the diameter of the wire he found to be unfavourable to the effect, in consequence of the increase of the cooling power of the atmosphere. (Ann. of Phil. vi. 209.)

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* On the quantity of coated surface required for igniting different lengths of wire, the reader may consult Mr. Cuthbertson's book, p. 161, &c.

When the power of an electrical battery is increased, metallic wires, by transmitting the discharge through them, may be melted and dispersed in the form of smoke, or of an impalpable powder lighter than air. The galvanic discharge, also, is capable of fusing metallic wires; but being less violent, it does not scatter their particles to a distance. Even wire formed of the most infusible of the metals, platinum, acquires a white heat, and melts into globules.

With a still more powerful electrical battery (one for example containing about 18 square feet) metallic wires are not only melted, but undergo absolute *combustion*. Lead and tin wire emit a yellow light, and copper and silver a green one. If the experiment be made on wire confined in a glass receiver, which contains a measured quantity of air, the bulk of the air, and its proportion of oxygen, are both found to be diminished.* The metals are converted into oxides of different colours: lead, tin, and zinc, into white oxides; platinum, gold, silver, and copper, into oxides of a dark colour. The experiment may be pleasingly varied by passing the discharge through wires, stretched over planes of glass or sheets of paper, at a small distance from their surface. The metallic oxide which is produced is forcibly driven into the glass or paper; and produces beautiful figures, varying in colour with the metal employed.† It appears, also, from Mr. Singer's experiments, that the oxides of some of the compound metals, when thus treated, (brass wire for instance) are exhibited in a completely separate state.

The combustion of metals may be effected, also, by galvanic electricity; but for this purpose the form of very thin leaves is preferable to that of wire. The plates, composing the galvanic trough, should, for this purpose, be not less than four inches square, the larger indeed the better; and several troughs should be joined together, so as to form an aggregate of not less than 100 or 150 pairs of plates. The galvanic influence is to be conveyed by wires brought from each extremity of the arrangement, and placed in contact with the opposite surfaces of the leaf. For the protection of the fingers, the wires should be enclosed in glass tubes. When thus exposed, the metals burn, or rather deflagrate, with great brilliancy.

Gold emits a very vivid white light, inclining a little to blue, and leaves an oxide, whose colour verges towards that of mahogany. Copper presents similar phenomena. The flame of silver is a vivid green, somewhat like that of a pale emerald, and the light is more intense than that of gold. Lead gives a vivid light of a dilute bluish purple. Tin a light similar to that of gold; and zinc a bluish white flame fringed with red.‡ In all these cases, provided the power be sufficiently strong, the deflagration is kept up for some time, without intermission.

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* Cuthbertson, p. 199.

† Cuthbertson, p. 226; and Wilkinson's Elements of Galvanism, in the 9th plate of which these appearances are represented.

‡ Philosophical Magazine, xi. 284, and xv. 96.

The most striking effect of the voltaic battery, is the vivid light which is produced by placing two pieces of charcoal, cut into the shape of pointed pencils, at the two ends of the wires of an interrupted circuit. When the battery is a very powerful one, and the charcoal points are brought within the 30th or 40th of an inch of each other, a bright spark is produced. By withdrawing the points from each other, a constant discharge takes place through the heated air, in a space equal to at least four inches, producing a most brilliant arch of light of considerable breadth, and in the form of a double cone. Platinum, introduced into this arch, melts as wax does in the flame of a candle. This light is more intense and vivid than any other that can be produced by art, and produces all the chemical effects of solar light. It does not arise from combustion, for the charcoal points are scarcely at all wasted by its continuance for some time.

But a much more important action is exerted by the electric and galvanic fluids, in disuniting the elements of several combinations. One of the first discoveries of the chemical agency of the pile was its power of decomposing water. Two pieces of any metallic wire are thrust through separate corks, which are fitted into the open ends of a glass tube in such a way that the extremities of the wires, when the corks are in their places, may not be in contact, but may be at the distance from each other of about a quarter of an inch (see fig. 77, *a.*)

If the parts of the wire, which project from without the tube, be made to communicate, the one with the zinc or positive end, and the other with the copper or negative end, of a galvanic battery, a remarkable appearance takes place. The wire, connected with the zinc or positive end of the pile or trough, where it is in contact with the water, if of an oxidable metal, is rapidly oxidized; while from the negative wire a stream of small bubbles of gas arises. But if the wires employed be of a metal which is not susceptible of oxidation, such as gold or platinum, gas is then extricated from both wires, and, by a simple contrivance, may be separately collected. The apparatus for this purpose is shown by fig. 76, where the wires *p* and *n*, instead of being introduced into a straight tube, are enclosed in a syphon, and terminate before they reach the end, in which a small hole is to be ground. When a stream of galvanic electricity is made to act upon water thus confined, oxygen gas is found, at the close of the experiment, in the leg connected with the positive end of the battery, and hydrogen gas in that connected with the negative end; and in the proportions which, by their union, compose water. At an early period of the inquiry, it was found, however, by Mr. Cruickshank, that the water surrounding the positive wire became impregnated with a little acid; and that round the negative wire with a little alkali. If instead of water we employ a metallic solution, the metal is revived round the negative wire *n*, and no hydrogen gas is liberated.

The gases constituting water, it was afterwards discovered by Sir H. Davy, may be separately produced from two quantities of water, not immediately in contact with each other. The fact is of peculiar importance, from its resemblance to other more recent ones, which have led that distinguished philosopher to the discovery of the general laws of electro-chemical action. Two glass tubes (*p* and *n*, pl. ix. fig. 79,) about one-third of an inch diameter and four inches long, having each a piece of gold wire sealed hermetically into one end, and the other end open, were filled with distilled water, and placed inverted in separate glasses filled, also, with that fluid. The two glasses, *a* and *b*, were made to communicate, either by dipping the fingers of the right hand into one glass, and those of the left into the other, or by interposing fresh animal muscle, or a living vegetable, or even moistened thread, as shown at *c*. The gold wires, projecting from the sealed ends of these tubes, were then connected, the one with the positive, the other with the negative end of the trough. Gas was immediately evolved from both wires. At the close of the experiment, in the tube *p* oxygen gas was found; in the negative tube *n* hydrogen. The proportions by measure were, as nearly as possible, those which result from the decomposition of water, *viz.* two of hydrogen to one of oxygen gas.* Now if these gases arose, as they necessarily must, from the decomposition of the same portion of water, that portion of water must have been contained either in the tube *p* or in the tube *n*. In the former case, the hydrogen gas, found after the process in *n*, must have passed invisibly from *p* to *n*, through the intermediate substance *c*. Or, if the water was decomposed in *n*, then the reverse process must have happened with respect to the oxygen: and it must have been transmitted, in a like imperceptible manner, from *n* to *p*. Facts of this kind, evincing the transference of the elements of a combination, to a considerable distance, through intervening substances, and in a form that escapes the cognizance of our senses, however astonishing, it will appear from the sequel, are sufficiently numerous and well established. It appears, also, from the experiments of Mr. Porrett, that water may be forced, contrary to its gravity, through the compact substance of a bladder, from the positive to the negative wire of a galvanic battery, composed of plates only 1¼ inch square.†

Different chemical compounds require, for the disunion of their elements, galvanic arrangements of various powers and intensities. The decomposition of water is easily effected by a series of fifty pairs of plates, each one or two inches square. But for those which remain to be described, instruments of much greater power are necessary.

The apparatus, employed in the masterly experiments of Sir H. Davy, which have laid the ground-work of this new science, was extremely simple. In cases, where liquid substances were operated upon, he employed occasionally the agate cups *p* and *n*, fig. 80, each of which was capable of holding about sixty grains of water. They were connected together, as shown in the figure at *a*, by the fibres of a peculiar flexible mineral called amianthus; and into each was inserted a platinum wire, the bent extremity of which is seen, in each figure, projecting above the cup. When the vessels were in actual use, the wire of *p* was connected with the zinc or positive end of a powerful galvanic series; and that of *n*, with the copper or negative extremity. For the agate cups two hollow gold cones were occasionally substituted (*p* and *n*, fig. 81,) the wire projecting from *p* being connected with the positive, and that from *n* with the negative end of a trough or series of troughs. Solid bodies were submitted to the galvanic influence, either by immersing small pieces of them in the gold cones; or, at other times, by making the cups themselves of the substance intended to be decomposed. Or if it was desirable to preserve them from contact with water, they were laid on a small insulated dish of platinum, with the inferior surface of which, immediately under the substance used, a wire from one end of the battery was connected, while the substance itself was made to communicate by another wire, with the opposite extremity of the apparatus.

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* Nicholson's Journal, 4to. iv. 276.

† Thomson's Annals, viii. 74.

When the gold cones were both filled with a solution of sulphate of potassa (a salt composed of potassa and sulphuric acid,) after exposure, during a sufficient time, to a powerful galvanic arrangement, pure potassa was found in the negative cone *n*, and sulphuric acid in the positive cone *p*. The decomposition was quite complete; for the liquid in *n* contained no acid, and that in *p* no alkali.

The experiment was repeated with several other neutral salts;[*] and with the invariable result, that the acid collected in the positive cone, and the alkali in the negative one. Strong solutions, or those in which the salt bore a considerable proportion to the water, were more rapidly acted upon than weak ones. Metallic salts were, also, decomposed. The acid appeared, as before, in the positive cone, and the metal was deposited, sometimes with a little oxide, in the negative one.

Salts, which are either insoluble, or very sparingly soluble, in water, had their elements disunited in the following manner. Cups were constructed of them, precisely resembling the gold cones, which, as the salts were hard and compact in their texture, was easily effected. These, after being filled with water, were connected, by platinum wires, with the opposite ends of a galvanic battery, the vessels themselves communicating, as before, by means of moistened amianthus. At the conclusion of the experiment, sulphuric acid (when the cups were made of sulphate of lime) was found in the positive cup, and lime water in the negative one. Sulphate of strontia, fluate of lime, and sulphate of baryta, were decomposed, though less easily, by the same expedient. In all these cases the acid element was found at the positive side, and the earthy one at the negative side, of the arrangement.

These facts evidently point out a transference of the elements of combinations from one electrified vessel or surface to another differently electrified. But the principle is made much more apparent by a little variation of the experiment. Thus, if solution of sulphate of potassa be electrified in the positive cone *p*, water alone being contained in *n*, after a sufficient continuance of the electrical action *p* will be found to contain diluted sulphuric acid; and the potassa will be discovered in the water of *n*. The alkali must necessarily, therefore, have passed, in an imperceptible form, along the connecting amianthus from the vessel *p* to the vessel *n*. Reversing the experiment, and filling *n* with solution of sulphate of potassa, the alkali remains in this cone, and the acid is transferred to the opposite side *p*. In one experiment, in which nitrate of silver was placed in the positive cup, and pure water in the negative one, the whole of the connecting amianthus was covered with revived silver.

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[*] Minute directions for exhibiting the transfer of acid and alkali, by means of a power not exceeding thirty pairs of two-inch plates, are given by Mr. Singer. (Nicholson's Journal, xxiv. 178.)

In the farther prosecution of the inquiry, Sir H. Davy succeeded in discovering a still more extraordinary series of facts. When an intermediate vessel (*i*, fig. 82) was placed between the positive and negative cups *p* and *n*, and was connected with both of them by moistened amianthus, it was found that acids may actually be made to pass from *n* to *p*, through the intermediate solution in *i*, without combining with it. Thus, solution of sulphate of potassa being put into the negative cup *n*, solution of pure ammonia into *i*, and pure water into *p*, in half an hour sulphuric acid was found in the water of the positive cup, though to have reached this it must have been transferred from *n* through the intermediate solution of ammonia. Muriatic acid, also, from muriate of soda, and nitric acid from nitrate of potassa, were transferred from the negative to the positive side through an interposed solution of alkali. And contrariwise, alkalies and metallic oxides were transmitted from the positive to the negative side, through intervening solutions of acids.

It is necessary, however, that the solution, contained in the intermediate vessel *i*, should not be capable of forming an insoluble compound with the substance intended to be transmitted through it. Thus sulphuric acid, in its passage from sulphate of potassa in the negative cup through the vessel *i* containing a solution of pure baryta, is detained by the baryta, and falls down in the state of an insoluble compound with that earth.

Bodies, the composition of which is considerably more complicated, are also decomposed by galvanic electricity. Thus from certain minerals, containing acid and alkaline matter in only very minute proportion, these ingredients are separately developed. Basalt, for example, (a kind of stone which, in 100 grains, contains only 3½ grains of soda and half a grain of muriatic acid), gave, at the end of ten hours, evident traces of alkali round the negative, and of acid round the positive wire. A slip of glass, also, negatively electrified in one of the gold cones, had soda detached from it, and sustained a loss of weight.

It may now be understood why, by the agency of galvanism on water, alkali appears at the negative and acid at the positive wire.

The fact was, for some time, not a little perplexing to Sir H. Davy; till, at length, he ascertained that all water, however carefully distilled, contains neutral salts in a state of solution. From these impurities, the alkaline and acid elements are separated, agreeably to a law which has already been explained. In the same way, and by the decomposition, also, of the glass vessel, which Davy found to be corroded at its point of contact with the platinum wire, the muriatic acid and alkali are accounted for, which some chemists have obtained by galvanizing what was before considered as pure water; a fact which has been urged in proof of the synthetical production of both those bodies. Absolutely pure water, it has been demonstrated by the same great philosopher, yields nothing but hydrogen and oxygen gases.

All the effects of galvanic arrangements, in producing chemical decompositions, it has been found, may be obtained by ordinary electricity. Its adaptation to this purpose was first successfully attempted by Dr. Wollaston.* The apparatus, which he employed, was similar to that already represented (fig. 77, *a*), excepting that the wires, instead of being exposed to the fluid contained in the tube, throughout their whole length, were covered with wax, and the points only were laid bare. Or (which was found to answer still better) the wires were enclosed in capillary glass tubes, which were sealed at their extremities, and then ground away, till the points alone were exposed. The conducting wires, thus arranged, were then introduced into a tube, or other vessel containing the liquid to be operated on, and were connected, the one with the positive, the other with the negative, conductor of an electrical machine, disposed for positive and negative electricity.† When solution of sulphate of copper was thus electrized, the metal was revived round the negative pole. On reversing the apparatus, the copper was redissolved, and appeared again at the other wire, now rendered negative.

When gold wires, from $\frac{1}{700}$ to $\frac{1}{1500}$ of an inch in diameter, thus enclosed, were made to transmit a stream of electricity, a succession of sparks afforded a current of gas from water. When a solution of gold in nitro-muriatic acid was passed through a capillary tube; the tube then heated to drive off the acid; and afterwards melted and drawn out,—it was found that the mere current of electricity, without sparks, evolved gas from water. The analogy, however, between the effects of ordinary and galvanic electricity is not quite perfect, inasmuch as, by the former, both hydrogen and oxygen gases are evolved from each wire, instead of being formed separately, as by the voltaic apparatus.

Sir H. Davy has since proved, that by a similar apparatus, solution of sulphate of potassa is decomposed, potassa appearing at the negative, and sulphuric acid at the positive pole.‡

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* Philosophical Transactions, 1801.

† See Cuthbertson's Practical Electricity.

‡ Philosophical Transactions, 1806.

SECTION IV.

Theory of the Changes produced by Galvanic Electricity.

A fact of considerable importance, in explaining the phenomena that form the subject of the last section, was discovered several years ago by Mr. Bennett, and has since been confirmed by the experiments of Volta and Davy. Different bodies, it is found, acquire, when brought into contact, either by their whole surfaces or by a single point, different states of electricity. The best method of performing the experiment is to take two discs or plates, the one of copper, the other of zinc, each about four inches diameter, and furnished with an insulating glass handle; to apply them for an instant to each other by their flat faces; and afterwards to bring them separately into contact with the insulated plate of the condensing electrometer. The instrument indicates, by the divergence of its gold leaves, the kind of electricity acquired by each of the plates, which in the zinc plate is shown to be positive, and in the copper plate negative.*

It had been established, also, by Sir H. Davy, in 1801, that when a galvanic arrangement *of the second kind* is constructed, by alternating metallic plates with strata of different fluids, alkaline solutions always receive electricity *from* the metal, and acids, on the contrary, transmit it *to* the metal. When an arrangement, for example, is made of water, tin, and solution of potassa, the current of electricity is from the tin to the alkali. But, in an arrangement of nitric acid, tin, and water, the circulation of electricity is from the acid to the tin. If, then, the alkali, after having acquired electricity from the metal, could be suddenly separated from the combination, there can be no doubt that it would be found in a positive state. For the contrary reason, the acid, having given electricity to the metal, must, if it could be detached, be found negative.

Still more satisfactory evidence has been since obtained of the electrical state of the acids and alkalies, by examining what kind of electricity they impart to an insulated metallic plate. Various dry acids, being touched on an extensive surface by a plate of copper insulated by a glass handle, the copper was found, after contact, to have become positively electrified, and the acid negatively. On the contrary, making the experiments with dry earths in a similar manner, the metal became negative. The alkalies gave less distinct results, owing to their attraction for moisture. Bodies, moreover, possessing opposite electrical energies towards one and the same body, are found to possess them with regard to each other. Thus, when lime and oxalic acid were brought into contact, the earth was found to be positive, and the acid negative. Sulphur appears to be in the positive state. Oxygen, judging from those compounds in which it is loosely combined, is negative; and hydrogen, by the same test, positive.

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* Volta, in Nicholson's Journal, 8vo. i. 136. Wilkinson, ii. 40, 50, 131. Cuthbertson, 267.

Now, if the common laws of electrical attraction and repulsion operate, as there is every reason to believe they must, among bodies so constituted, it will follow that hydrogen, the alkalies, metals, and oxides, being positively electrified, will be repelled by surfaces which are in the same state of electricity as themselves, and will be attracted by surfaces that are negatively electrified. And, contrariwise, oxygen, and the acids (in consequence of the oxygen they contain,) being in a negative state, will be attracted by positive surfaces, and repelled by negative ones.

To apply this theory to the simplest possible case, the decomposition of water, the hydrogen of this compound, being itself positively electrified, is repelled by the positive wire, and attracted by the negative one; while, on the contrary, oxygen, being negative, is repelled by the negative wire, and attracted by the positive one. The flame of a candle, which consists chiefly of ignited charcoal, when placed between a positive and negative surface, bends towards the latter; but the flame of phosphorus, consisting chiefly of acid matter, when similarly placed, takes a direction towards the positive surface. In the case of neutral salts, the negative acid is attracted by the positive wire; and the positively electrified alkali by the negative wire.

Thus then a power has been discovered, superior in its energy to chemical affinity, and capable either of counteracting it, or of modifying it, according to circumstances. The chemical attraction between two bodies may be destroyed by giving one of them an electrical state opposite to its natural one; or the tendency to union may be increased by exalting the natural electrical energies.

All bodies, indeed, that combine chemically, so far as they have hitherto been examined, have been found to possess opposite states of electricity. Thus copper and zinc are in opposite states to each other; so are gold and mercury; sulphur and metals; acids and alkalies. By bringing two bodies into the same electrical state, which were before capable of union, we destroy their tendency to combination. Thus zinc, or iron, when negatively electrified, will not unite with oxygen. Even after combination, it is thought by Sir H. Davy not improbable that bodies may still retain their peculiar states of electricity. If oxygen prevail, in any compound, over the combustible or positive base, the compound is negative, as in certain metallic oxides. But the combustible ingredient may be in such proportion as to predominate, and to give to the compound a positive energy. When precise neutralization is attained, bodies that had before exhibited electrical effects are deprived of this property.

It is an interesting question, but one which can scarcely be determined in the present state of the science, whether the powers of electrical attraction and repulsion, exerted between the ultimate particles or atoms of different bodies, be identical, as Sir H. Davy has suggested, with chemical affinity; or whether it may not rather be considered, like caloric, as a distinct force, which only modifies that of chemical attraction. On the former hypothesis, two bodies, which are naturally in opposite electrical states, may have these states sufficiently exalted to give them an attractive force superior to the cohesive affinity opposed to their union; and a combination may take place, which will be more or less energetic, as the opposed forces are more or less equally balanced. Again, when two bodies, repellent of each other, act upon a third with different degrees of the same electrical energy, the combination will be determined by the degree. Or, if bodies, having different degrees of the same electrical energy with respect to a third, have likewise different energies with respect to each other, there may be such a balance of attracting and repelling forces as to produce a triple compound.

This hypothesis, it is remarked by Sir H. Davy, agrees extremely well with the influence of *mass*, which has been so well illustrated by Berthollet; for many particles, acting feebly, may be equal in effect to fewer acting more powerfully. Nor is it at all contradictory to the observed influence of caloric over chemical union; for an increase of temperature, while it gives greater freedom of motion to the particles of bodies, exalts all their electrical energies. This Sir H. Davy ascertained with respect to an insulated plate of copper and another of sulphur, when heated below 212° Fahr.; and, at a still higher temperature, these bodies, as is well known, combine, with the extrication of heat and light, the usual accompaniments of intense chemical action.

It cannot, however, be admitted, that this ingenious theory has yet been demonstrated. On the contrary, it rests on the supposition of opposite electrical states of the atoms of bodies, excited by contact, and permanent even after combination, which cannot be proved to exist. Of the existence of attractive forces between the atoms of different bodies, we have better evidence, and we may still consider chemical affinity, exerted between atoms of different kinds, as the cause of chemical combination.

On the supposition that electricity is a force which only modifies the action of chemical affinity, we may regard it, when it promotes combination, as producing this effect by counteracting cohesive attraction. When it impedes combinations, or destroys those which are already formed, it probably acts as a force co-operating with elasticity.

SECTION V.

Theory of the Action of the Galvanic Pile.

Two theories have been framed to account for the phenomena of the Galvanic Pile, and of all similar arrangements. The first, originating with Volta, was suggested by the fact, which may be considered, indeed, as fundamental to it—that electricity is excited by the mere contact of different metals. When a plate of copper and another of zinc are made to touch by their flat surfaces, as was stated in the last section, the zinc, after separation, exhibits positive electricity, and the copper negative. It is natural, therefore, to conclude, that a certain quantity of electricity has moved from the copper to the zinc. On trying other metals, Volta found that similar phenomena take place; and, by a series of experiments, he was led to arrange their powers in the following order, it being understood that the first gives up its electricity to the second; the second to the third; the third to the fourth; and so on.

Silver.
Copper.
Iron.
Tin.
Lead.
Zinc.

The metals, then, have been denominated by Volta, from this property, *motors* of electricity; and the process, which takes place, *electro-motion*, a term since sanctioned by the adoption of it by Sir H. Davy.

It is on this transference of electricity from one body to another by simple contact, that Volta explains the action of the instrument discovered by himself, and of all similar arrangements. The interposed fluids, on his hypothesis, have no effect as chemical agents in producing the phenomena, and act entirely as conductors of electricity. Without disputing, however, the accuracy of the facts which suggested his theory, it is sufficient for its refutation that it is irreconcilable with other phenomena, and especially with the observation that the chemical agency of the liquids, on the more oxidizable metal of galvanic arrangements, is essential to their sustained activity. It has been proved, indeed, that the phenomena begin and terminate with the oxidation, and that the energy of the pile bears a pretty accurate proportion to the rapidity of the process. Hence it seems, on first view, an obvious inference, that the oxidation of the metal is the primary cause of the evolution of electricity in galvanic arrangements. It has been proved, however, that it is not necessary to the excitement of common electricity, that the amalgam should be oxidated; for the machine continues to act when enclosed in hydrogen gas or carbonic acid. The electric column of M. de Luc is composed of dry substances; but, even in this instrument, the oxidation of the metals appears to be essential to its activity, for when the column is hermetically confined in a given portion of air, the phenomena cease in time, in consequence of the loss of its oxygen.

But, though the chemical agency of the fluids which are employed is now admitted, on all hands, to be essential to the excitement of galvanic electricity, yet it is by no means universally agreed that we are to consider that agency as the first in the order of phenomena. It has been suggested by Sir H. Davy, as a correction of the theory of Volta, that the electro-motion, occasioned by the contact of metals, is the primary cause of the chemical changes; and that these changes are in no other way efficient than as they restore the electric equilibrium. To explain this, let us suppose that in any three pairs of plates of a galvanic trough, the zinc plates, z 1, z 2, z 3, (fig. 78) are in the state of positive, and the copper plates, c 1, c 2, c 3, in that of negative electricity. The liquid, in any cell after the first, will be in contact, on the one side, with positively electrified zinc, and on the other with negatively electrified copper. And, if the elements composing the fluid be themselves in different states of electricity, the negatively electrified element will be attracted by the zinc, and the positively electrified element by the copper. Thus, when solution of muriate of soda in water is the fluid, the oxygen and the acid will pass to the zinc, or positive plate, and the alkali to the copper one; while the hydrogen, having no affinity for copper, escapes. The electric equilibrium will be restored, but only for a moment; for, as the interposed fluid is but a very imperfect conductor of electricity, the zinc and copper plates will, by their electromotive power, again assume their states of opposite electricity; and these changes will go on as long as any muriate of soda remains undecomposed. In a Voltaic arrangement, therefore, the electrical energies of the metals with respect to each other, or to the substances dissolved in water, are the causes disturbing the equilibrium; and the chemical changes are the causes that restore it.

No theory of the galvanic pile, however, can be considered as complete, that does not account for the accumulation of electricity at the zinc end of the apparatus. On the theory that the oxidation of the zinc is the source of the evolved electricity, the fact has been ingeniously explained by Dr. Bostock. He takes it for granted that the electric fluid has an affinity for hydrogen, and supposes that the electricity, evolved at the surface of the first zinc plate, is carried, united to hydrogen, through the fluid of the cell, to the opposite copper plate. Here the hydrogen and electricity separate; the former flies off in the state of gas, and the latter passes onwards to the next zinc plate. Being in some degree accumulated in this plate, it is disengaged by the action of the fluid in a more concentrated state than before. And in the same manner, by multiplying the number of pairs, it may be made to exist, in the zinc end of the pile, in any assignable degree of intensity.

On this theory, the electricity evolved is actually *generated* by the chemical action of the interposed fluids on every zinc plate of the series; and its accumulation is the aggregate of what is thus evolved. The concentration, which takes place at the zinc end of the arrangement, admits, however, of being explained by the hypothesis of Volta, especially as modified by Sir H. Davy. Taking the first cell as an example, the fluid interposed between the positive zinc plate, z 1, fig. 78, and negative copper plate, c 2, being itself a conductor of electricity, must in time produce an equilibrium between these two plates; but this can only be done by the passage of a certain quantity of electricity across the fluid. The absolute quantity of electricity will, therefore, be diminished in the first pair, and increased in the second. In like manner, the second zinc plate will give up part of its electricity to the third copper plate, and the second pair of plates will be deprived of part of its electricity. The electricity, thus lost by the second pair, it will regain from the first pair of plates. By multiplying, in this way, the number of plates, every successive pair, as we advance in the series, has a tendency to diminish the quantity of electricity in the first, and to have its own state of electricity proportionally exalted.

When a communication is made between two extremities of a series, for example between z^3 or its contiguous cell, and c^1, the opposite electricities tend to an equilibrium. The third pair gives up a share of its electricity to the first; and the intermediate pair, being placed between equal forces, remains in equilibrio. Hence, in every galvanic arrangement, there is a pair of plates at the centre, which is in its natural state of electricity. The effect of such a communication must necessarily be to reduce the pile to a state of inactivity, if there did not still exist some cause sufficient to destroy the equilibrium. On the hypothesis of Volta, this can be nothing else than the property of electro-motion in the metals, which originally produced its disturbance.

Such are the hypotheses that have been framed to explain the phenomena of the Voltaic pile. In the present state of the science, neither of them is entitled to be received as altogether satisfactory; and I have stated them rather with the view of exciting than of satisfying inquiry.[*] On the theory of galvanic electricity, it only remains to point out its difference from the electricity developed by ordinary processes; and to explain the different effects which are produced by varying the size of the plates in galvanic arrangements.

Though the identity of common and galvanic electricity appears to be sufficiently established, yet in some of their phenomena, which have already been described, there is a considerable difference. To explain these, it was long ago suggested by Mr. Nicholson,[†] that the electricity excited by the common machine is developed in much smaller quantity, but in a higher state of concentration or intensity than the electricity of galvanism. Hence its velocity is much more rapid; and hence it readily passes through plates of air and other non-conductors, that are scarcely permeable by galvanic electricity. By virtue of the same property, it disperses the metals in the form of smoke; while the utmost effect of a Voltaic arrangement is to melt them into globules. By doubling the quantity of galvanic electricity, also, we ignite only a double length of metallic wire, and the ignition is more permanent; but the intensity of common electricity is such, that, by doubling its quantity, we ignite four times the length of wire, and the effect is little more than momentary. (Cuthbertson, p. 278.)

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[*] The reader, who wishes to pursue the subject, may consult an essay by the author, in Nicholson's Journal, xxxv. 259; M. De Luc's papers, xxxii. 271, and xxxvi. 97; Mr. Singer on the Electrical Column, xxxvi. 373; and his work on Galvanic Electricity; Dr. Bostock's Essay in Thomson's Annals, iii. 32; Sir H. Davy's chapter on Electrical Attraction and Repulsion, in his Elements of Chem. Philos. p. 125; and the 1st vol. of Gay Lussac and Thenard's Recherches.

[†] See his Journal, 4to. iv. 244.

The comparative quantities of electricity evolved by the common machine and by a Voltaic apparatus, have been made a subject of calculation by Mr. Nicholson. A pile, consisting of 100 half crowns, with the same number of pieces of zinc, produced, he found, 200 times more electricity than could be obtained, in an equal time, from a 24 inch plate machine in constant action. Van Marum has also observed, that a single contact of a Leyden jar or battery with a Voltaic pile charges it to the same degree as six contacts with the prime conductor of a powerful machine.

It might naturally be expected that a proportion would be observed between the quantity of surface composing galvanic arrangements, and their power of action; and such, with some limitation, is the fact. With plates of the same size, the effect, generally speaking, is proportioned to the number. But, by enlarging the size, without increasing the number, neither the shock nor the power of decomposing water and other imperfect conductors, is proportionally increased. A remarkable proof of this is, that Mr. Children's great battery of 20 double plates, 4 feet by 2, had no more effect on the human body, or in decomposing water, than a battery containing the same number of small plates. On the contrary, to obtain a great increase of effect in the combustion of metals, it is necessary to enlarge considerably the size of the plates. Thus 100 plates of four inches square produce, in this way, an incomparably greater effect than the same surface divided into four times the number.

The effect of multiplying the number of plates, it has already been observed, is, that we obtain electricity of a higher intensity, and it was supposed by Volta* that the proportion is, as nearly as can be judged, an arithmetical one. If, for example, we have a certain intensity with 20 pairs, it should be doubled by 40, trebled by 60, and so on. It has been shown, however, by Sir H. Davy,† that by increasing the number of plates, the quantities of gas, evolved from water, were nearly as the squares of the numbers. By a sufficient increase, the most astonishing effects may be produced. Thus the combination belonging to the Royal Institution, which contains 2000 double plates, each having a surface of 32 square inches, when in action, melts platinum as easily as wax is melted by a candle, and fuses quartz, the sapphire, lime, and magnesia. By enlarging the size, without increasing the number, it has also been shown that we gain, not in intensity, which remains exactly the same, but in quantity. Now, for the combustion of metals, what we principally want is a large quantity of electricity; for, as they are perfect conductors, it finds a ready passage through them, even when of low intensity. On the contrary, to find its way through fluids and other imperfect conductors, it must be evolved in a high state of concentration. The facts, therefore, accord sufficiently well with the explanation, to entitle it to be received as a probable hypothesis.

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* Nicholson's Journal, 8vo. i. 139.

† Elements of Chem. Philos. p. 155.

SECTION VI.

Of Electro-Magnetic Phenomena.

All the effects of galvanic arrangements, that have hitherto been described, are produced in bodies when interposed between the extremities of conductors proceeding from the positive and negative poles; in other words, so placed that the galvanic current is *imperfectly* continued through the body intended to be acted upon. It was not known that the electric current, passing *uninterruptedly* through a wire connecting the two ends of a galvanic battery, is capable of being manifested by any effect, till Professor Oersted, of Copenhagen, in the winter of 1819, discovered an unequivocal test of its passage in its effect on the magnetic needle. The opposite poles of a battery of sufficient magnitude, in full action, were joined by a metallic wire, which, for shortness, he calls the *uniting conductor*, or *uniting wire*. This wire was either placed horizontally, (see pl. iv. fig. 37,) or bent in any other direction required by the nature of the experiment. When the wire was placed horizontally *over*, and parallel to a magnetic needle properly suspended, and at a distance not exceeding three quarters of an inch, the needle was moved, and the end of it next to the negative pole of the battery turned westwards. The circumstances of the experiment remaining in every respect the same, except that the uniting wire was placed *under* the needle instead of over it, the declination of the needle was in an opposite direction; for the pole next the negative end of the battery now turned eastwards. Again, when the connecting wire and needle were situated in the same horizontal plane, no declination took place, either to the east or west, but an *inclination*, or vertical dip of the needle, was observed. When the uniting wire was west of the needle, the pole next to the negative end of the battery was depressed; when the wire was to the east, the same pole was elevated.

When the uniting wire was situated perpendicularly to the plane of the magnetic meridian, the needle, whether above or below the wire, remained at rest, unless the pole were very near the wire. In that case, the pole was *elevated*, if the negative electricity entered from the west side; and *depressed*, if from the east. M. Von Buch has since, however, shown that this state of rest does not continue in two of the four positions of the wire, provided a sufficient galvanic power be employed in the experiment. (Ann. of Phil. N. S. ii. 285.)

When the uniting wire was perpendicularly opposite to the north pole of the suspended needle, and the upper extremity of the wire connected with the *negative* end of the battery, the pole, when brought near the wire, moved towards the east. But when the wire was opposite to a point between the pole and the middle of the needle, the pole moved westwards. When the upper end of the wire was made to receive *positive* electricity, the phenomena were reversed.

The amount of these effects diminished with the decreasing power of the battery, and with the distance of the needle from the uniting wire. This wire, it was found, may consist of almost any metal; nor does it lose its effect, though interrupted by a column of water, provided the column does not extend to several inches in length. It is remarkable, also, contrary to what is observed in any other effect of electricity or galvanism, that the influence of the uniting wire passes to the needle through plates of glass, metal, or wood, the disc of an electrophorus, or a stone-ware vessel of water; nor does the sudden interposition of any of these bodies destroy or sensibly diminish the effect. On needles of brass, glass, or gum lac, no effect whatever is produced.

The common electrometer indicates the tension or intensity of electricity; but, till the discovery of M. Oersted, we had no instrument to show the direction of its current. The effect on the needle depends, indeed, entirely on the current. So long as this current is interrupted, no effect is produced on the needle; but the moment it is restored, the north pole of the needle is turned to the left of the observer, supposing him to have his face directed towards that pole. This may be more briefly expressed by saying, that the north pole is carried to the left of the current which acts upon the needle. We thus acquire a *galvanometer*, capable of pointing out the direction of the electric current under all circumstances.

By an instrument nicely constructed on this principle, M. Ampère ascertained that the current in the Voltaic battery itself, from the negative to the positive extremity, has the same influence on the needle as that current, which in the uniting wire goes, on the contrary, from the positive to the negative pole. This is best shown by two needles, the one placed upon the pile, the other above or under the conductor. In each, the north pole of the needle will be seen turned to the left of the current near which it is placed: the two needles are both carried to the same side, and are nearly parallel, when one is above the pile, and the other beneath the conductor.

When two rectilinear portions of two conducting wires, joining the extremities of two Voltaic piles, are so disposed that the one is fixed and the other suspended so as to be moveable, the latter will approach the former if the currents be in the same sense, and will be repelled when the currents are in opposite directions. In common electrical attractions and repulsions, electricities of the same name are mutually repulsive, and opposite electricities attract each other. But in the attractions and repulsions of electric currents it is precisely the reverse, the repulsion taking place only when the wires are so situated that the currents are in opposite directions. The attractions and repulsions of these currents, unlike the mutual action of bodies electrized in the common way, take place equally *in vacuo* as in air.

The discovery of M. Oersted was limited to the action of the electric current on needles previously magnetized. But it was afterwards, and about the same time, ascertained, both by Sir H. Davy and M. Arago, that magnetism may be developed in steel, not previously possessing it, by being placed in the electric current, and may even be excited in the uniting wire itself. Both philosophers ascertained, independently of each other, that the uniting wire, becoming a magnet, attracts iron filings, and collects sufficient to acquire the diameter of a common quill. The moment the connexion is broken, all the filings drop off;* and the attraction diminishes also with the decaying energy of the pile. Filings of brass or copper, or wood shavings, are not attracted at all.

The communication of magnetic properties to a steel needle was effected by Sir H. Davy and M. Arago in different ways. The former observed that steel needles, placed upon the connecting wire, became magnetic; those parallel to the wire acted like the wire itself; those placed across it each acquired two poles. Such as were placed *under* the wire, the positive end of the battery being east, had north poles on the south of the wire, and south poles to the north. The needles *above* were in the opposite direction, and this was constantly the case, whatever might be the inclination of the needle to the wire. On breaking the connexion, the steel needles placed *across* the uniting wire retained their magnetism, while those placed *parallel* to it lost it at the moment of disunion. Contact with the uniting wire was not found necessary, for the effect was produced though thick glass intervened. Increasing the size of the plates of the battery increased the magnetic effect of the connecting wires; thus the wire, uniting the poles of a battery of 60 pairs of plates, did not take up half so much filings, as when the battery was arranged so as to form 30 pairs of twice the size.

Similar effects were produced in Sir H. Davy's experiments by the electricity excited by a common machine. A battery of 17 square feet, discharged through a silver wire 1-20th of an inch diameter, rendered bars of steel, two inches long and from 1-10th to 1-20th thick, so magnetic as to lift up pieces of steel wire and needles; and the effect was communicated to needles at the distance of five inches from the wire, even with the intervention of water or of thick plates of glass or metal. Various other important facts respecting the communication of magnetism are described in the paper of the same author, published in the Philosophical Transactions for 1821, all tending to establish the conclusion that magnetism is produced whenever concentrated electricity is passed through space.

On the suggestion of M. Ampère, M. Arago communicated magnetism to the needle in a different manner. A copper wire, by being rolled round a solid rod, was twisted into a spiral, so as to form a *helix*. It was easy, by passing the wire round the rod, in one direction or the other, to form a *dextrorsal* helix, proceeding from the right hand towards the left, as in the tendrils of many plants; or a *sinistrorsal*, or left helix, proceeding downwards from the left hand to the right above the axis. Into the cavity of a spiral thus formed, connecting the two poles of a battery, a steel needle wrapped in paper was introduced; and, in order to exclude all influence of the magnetism of the earth, the conchoidal part of the wire was kept constantly perpendicular to the magnetic meridian. In a few minutes the needle had acquired a sufficiently strong dose of magnetism; and the position of the north and south poles exactly agreed with M. Ampère's notion, that the electric current traverses the connecting wire in a direction from the zinc extremity of the pile to the copper extremity.

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* M. Arago afterwards determined that the wire retains its magnetism for a few instants after the connexion is broken, but that it soon ceases.

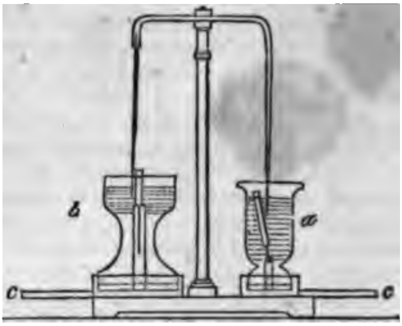
In another experiment, using one copper wire, two symmetrical spirals were formed, each nearly two inches long, and separated by a rectilinear piece of the same metal, the spirals of the two being turned in contrary senses. Within each of these spirals a needle, properly guarded, was included, and the connexion made between the two ends of a galvanic battery. The result was, that both the needles were magnetized, but in exactly opposite senses. When a right helix had been used, that end of the needle which had been placed towards the negative pole of the battery pointed to the north, and the other end to the south; but with a left helix, that end of the needle which had been nearest the positive pole of the battery pointed north, and the other end south. In one case, when the connecting wire had been twisted into three consecutive helices, the middle one being different from the other two, a single piece of steel wire, sufficiently long to pass through all three, being enclosed in a glass tube, was placed within them. On being removed, it was found to have acquired six poles: first a north pole, a little further on a south pole, then another south pole, a north pole, another north pole, and at the further end a south pole.

The electricity of a common machine, it was afterwards ascertained by the Chev. Yelin, when passed along a helix, either in simple electrical sparks or discharges from a battery, has the effect of rendering an included needle magnetic. In varying these experiments, M. Bockman ascertained that no modification of the effect was produced by altering the diameter of the helix from half an inch to 13 inches. With a helix of 34 inches diameter, and a coated surface of 300 square inches, much less magnetism was, however, imparted; and with one of 84 inches it was scarcely perceptible. It was found that a needle outside of the helix was magnetized as much as one within; that after being once fully magnetized, a continuation of the discharges diminished its power; and that five jars, each of 300 square inches, did not produce, by repeated discharges, much more effect than one of them.

Any wire, through which a current of electricity is passing, has a tendency to revolve round a magnetic pole, in a plane perpendicular to the current; and that, without any reference to the axis of the magnet, the pole of which is used. Also a magnetic pole has a tendency to revolve round such a wire.

Suppose the wire perpendicular, its upper end positive, or attached to the positive pole of a Voltaic battery, and its lower end negative; and let the centre of a watch dial represent the magnetic pole:

if it be a north pole, the wire will rotate round it in the direction that the watch hands move; if it be a south pole, the motion will be in the opposite direction. From these two, the motions which would take place if the wire were inverted, or the pole changed or made to move, may be readily ascertained, since the relation now pointed out remains constant.

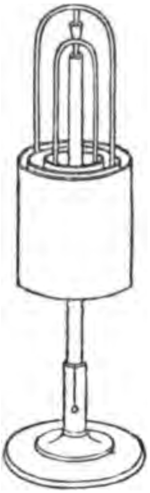


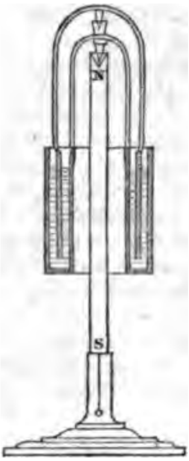
The apparatus in the sketch is the ingenious invention of Mr. Faraday, and is intended to illustrate these motions. The central pillar supports a piece of thick copper wire, which, on the one side, dips into the mercury contained in a small glass cup, *a*. To a pin at the bottom of this cup a small cylindrical magnet is attached by a piece of thread, so that one pole shall rise a little above the surface of the mercury, and be at liberty to move round the wire. The bottom of the cup is perforated, and has a copper pin passing through it, which, touching the mercury in the inside, is also in contact with the wire that proceeds outwards on that side the instrument. On the other side of the instrument, *b*, the thick copper wire, soon after turning down, terminates, but a thinner piece of wire forms a communication between it and the mercury in the cup beneath. As freedom of motion is required in this wire, it is made to communicate with the former by a ball and socket joint, the ball being held in the socket by a piece of thread; or else the ends are bent into hooks, and the one then hooked on to the other. As good metallic contact is required, the parts should be amalgamated, and a small drop of mercury placed between them, and the lower ends of the wire should also be amalgamated. Beneath the hanging wire a small circular magnet is fixed in the socket of the cup, *b*, so that one of its poles is a little above the mercury. As in the former cup, a metallic connexion is made, through the bottom, from the mercury to the external wire.

If now the poles of a battery be connected with the horizontal external wires, *c c*, the current of electricity will be through the mercury and the horizontal wire on the pillar which connects them, and it will now be found that the moveable part of the wire will rotate round the magnetic pole in the one cup, *b*, and the magnetic pole round the fixed wire in the other cup, *a*, in the direction before mentioned.

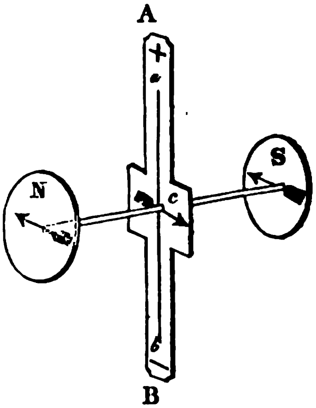
By using a delicate apparatus, the magnetic pole of the earth may be made to put the wire in motion. The rotation then takes place round a line parallel to the dipping needle: hence the rotating wire must always be inclined, so that the solid it describes in revolving, if a cone, and not a mere circle, should include a line parallel to the dip which passes through its apex.

Another ingenious contrivance for illustrating the rotatory motion of the wire round the pole of a magnet, has been invented by M. Ampère, and has the advantage of comprising within itself the Voltaic combination which is employed. It consists of a cylinder of copper about two inches high, and 1¾ internal diameter, within which is a smaller cylinder about 1 inch diameter. (See the woodcut.) The two cylinders are fixed together by a bottom, having a hole in its centre the size of the smaller cylinder, leaving a circular cell, which may be filled with acid. A piece of strong copper wire is fastened across the top of the inner cylinder, and from the middle of it rises at a right angle a piece of copper wire, supporting a very small metal cup containing a few globules of mercury. A cylinder of zinc, open at each end, and about 1¼ inch diameter, completes the Voltaic combination. To the latter cylinder a wire, bent like an inverted U, is soldered at opposite sides; and, in the bend of this wire, a metallic point is fixed, which, when fixed in the little cup of mercury, suspends the zinc cylinder in the cell, and allows it a free circular motion. On the suggestion of Mr. Barlow, Mr. Newman has fixed an additional point directed downwards from the central part of the stronger wire, which point is adapted to a small hole at the top of a bar magnet. When the apparatus with one point only is charged with diluted acid, and set on the end of a magnet placed vertically, the zinc cylinder revolves in a direction determined by the magnetic pole which is uppermost. With two points, the copper revolves in one direction, and the zinc in a contrary one. The magnet employed should be a powerful one.





As it is not easy always to bear in mind the direction in which the different poles of a magnet tend to revolve round the galvanised wire, or in which the wire tends to revolve round each respective magnetic pole, the following contrivance of Dr. Roget, which he has been so good as to communicate to me, will be found very use ful in aiding our conceptions, while studying the circumstances of an experiment, or anticipating the result of any new combination. A B, (see the wood-cut) is a slip of card, on each side of which a line, *a b*, is drawn along the middle of its length, the end *a* being marked +, the end *b* —, and the centre *c* being crossed by an arrow at right angles to it, directed as in the figure. Through the centre and at right angles to the plane of the slip of card, there is made to pass a slender stem of wood, at the two ends of which are fixed, in planes parallel to the slip of card A B, the circular discs of card, marked respectively with the letters N and S, and with arrows parallel to, but pointing in a contrary direction to the one at *c*. The same marks must be put on the reverse of each of the three pieces of card, so that, when held in different situations, they may be seen without turning the instrument.



If the line *a b* be supposed to represent the galvanic wire, (the direction of the current of electricity being denoted by the signs + and —, at the ends of the line,) the arrow at the centre will point out the direction in which it tends to move, when under the influence of the north pole of a magnet situated at N; or of a south pole situated on the other side at S; and, *vice versa*, the arrows at N and S will indicate the directions in which the north and south pole, respectively, tends to revolve round the galvanised wire in its vicinity, with relation to the direction of the current of electricity that is passing through it.

It must be observed that the poles N and S are here not considered as in connexion with each other, or as forming parts of one magnet; their operations are exhibited singly, and quite independently of each other. The advantage of this little instrument consists in its capability of being held in any situation, and thus easily adapted to the circumstances of any fact or experiment of which we may wish to examine the theory.

The above is but a very imperfect outline of the important facts already known respecting electro-magnetism; but it would lead me into details too extensive for this work to go farther into the subject. I refer, therefore, to the original memoirs of Oersted, (Ann. of Phil. xiii. and N. S. ii.); Arago, (Ann. de Chim. et Phys. xv. 93); Ampère, (Ann. de Chim. et Phys. xv. 59); Sir H. Davy, (Phil. Trans. 1821); Faraday, (Quart. Journ. xii. 47, 416); and others. Those, who wish only for a general view of the subject, will find it in an "Historical Sketch of Electro-Magnetism," published in the 2d and 3d volumes, N. S. of the Annals of Philosophy. It is necessary, however, before dismissing the subject, to offer a brief view of the explanation which has been given of the leading phenomena.

The theory of Oersted, which, though it appears to have led him to his principal discoveries, is not stated in a very intelligible manner, rests on the assumption of two different and opposite electricities, positive and negative, the former of which is developed by the more oxidizable, the latter by the less oxidizable metal of galvanic arrangements. Each of these forces has a repulsive activity for itself, and an attractive activity for the opposite force. In the wire connecting the two opposite poles of a galvanic battery, and in the space around it, there are, he supposes, two currents, the one of positive, the other of negative electricity, moving in spiral and opposite directions; and an effect is supposed to take place in the wire and around it, dependent on the union of these electricities, to which he gives the name of the *electric conflict*. By this conflict, all non-magnetic bodies appear to be penetrable, while magnetic bodies, or rather their magnetic particles, resist its passage, and are, therefore, moved by the impetus of the contending powers. All the effects on the north pole of the needle may be understood by supposing that negative electricity moves in a spiral line bent to the right, propelling the north pole, but not acting on the south pole. To positive electricity a contrary motion is ascribed, and a power of acting on the south pole, but not on the north. This theory requires, therefore, that there be two electric fluids; but in the opinion of Dr. Wollaston, which on every obscure topic of science is entitled to the greatest deference, the phenomena may be equally well explained by a single electro-magnetic current, passing round the axis of the wire, in a direction determined by the position of the Voltaic poles. The assumption of such a current is, it must be confessed, altogether gratuitous; but, without such a supposition, it is not easy to conceive any adequate cause for the motions that are observed in the magnetic needle, when brought within the influence of the uniting wire. Further researches will probably unfold the causes of these interesting phenomena, and will class them under general laws, founded on a more extensive induction of facts than we now possess, notwithstanding the zeal and genius that have already been devoted to the inquiry.

CHAPTER VI.

OF ELECTRO-NEGATIVE BODIES.

In conformity with the principle of arrangement, which has been explained in the Introduction, I shall commence with that class of simple bodies, the individuals of which are chiefly distinguished by the property of being attracted by positively electrified surfaces, and repelled by negative ones, and the natural state of which may, therefore, from the common laws of electrical attraction and repulsion, be inferred to be negative. They may be termed, for the sake of brevity, *electro-negative bodies*. Though highly important, from their extensive influence as chemical agents, yet their number is but small; for they consist only of OXYGEN, CHLORINE, IODINE, BROMINE, and a fifth body, which is only very imperfectly known to us, FLUORINE.

These bodies have been classed together from another circumstance of resemblance, that of being what has been termed *supporters of combustion*. But to the latter principle of arrangement may be objected the more extensive use, which is now made in chemistry, of the term *combustion*, to express all chemical combinations, which are accompanied with the extrication of heat and light. Now these appearances constantly attend the union of some of the simple combustible bodies with each other (sulphur and copper for instance); and we must seek, therefore, for analogies of a more comprehensive kind, on which to found the classification of chemical substances. In the present state of our knowledge, none appears to me preferable to that which distributes them into two great classes; the ELECTRO-NEGATIVE, or bodies that are attracted by the positive pole of a galvanic or electrical arrangement, which are the five already mentioned: and the ELECTRO-POSITIVE, or those that are attracted by the negative pole. The latter class, it will afterwards appear, contains a much greater number of individuals, and may itself, with great advantage to perspicuity and order, be divided into several subordinate genera.

SECTION I.

Of Oxygen.

We have no knowledge of the properties of oxygen in a state of complete separation. In the most simple form, under which we can procure it, it is combined with caloric, and probably with light and electricity, constituting oxygen gas.

This gas was discovered by Dr. Priestley in August 1774. He first obtained it from that oxide of mercury, which is produced by the long exposure of quicksilver to a boiling heat, and which had then the name of *mercurius calcinatus per se*. From 480 grains of this substance, he procured, by means of a burning glass, sixty ounce measures of gas. After investigating its properties with considerable skill, he gave it the name of *dephlogisticated air*. In the following year, Scheele discovered it, without any knowledge of the previous experiments of Priestley, and called it *empyreal air*. (Treatise on Air and Fire, xxxii.) It has been termed, also, *vital air*: but all these have given place to the name proposed by Lavoisier, which it now bears, and which, though objectionable on some accounts, it is scarcely desirable to change.

I. *Oxygen gas may be procured from various substances.*

1. From the black oxide of manganese, heated to redness in a gun-barrel, or in an iron or earthen retort.

It is not easy to lay down a general rule, as to the quantity of oxygen gas obtainable by heat from a given weight of peroxide of manganese of commerce, owing to the variable purity of that substance. Supposing it pure, 44 grains of peroxide should give 4 grains of oxygen gas, equal to about 12 cubic inches, and 40 of deutoxide should remain. Mr. Watt found that a pound (7000 grains) of the best Exeter manganese yielded generally about 1400 cubic inches of gas. An iron tube, when used for the first time, gives a less pure gas than afterwards, the carbonaceous matter of the iron, uniting with the oxygen, and being converted into carbonic oxide or acid. As manganese of commerce, also, is often contaminated with carbonate of lime, it is advisable, before using it, to wash it with muriatic or nitric acid diluted with 15 or 20 parts of water; then to edulcorate with distilled water; and afterwards to dry it at a moderate heat.

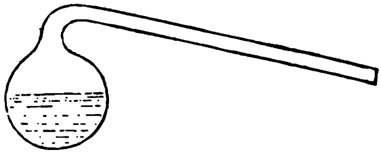
2. When only a small quantity of oxygen gas is wanted, it is better to act upon the peroxide of manganese with excess of sulphuric acid, less heat being then required, and the peroxide being converted into protoxide. Into a well cleaned Florence oil flask pour four ounces of strong sulphuric acid; after wiping the neck dry, add by degrees two ounces of finely-powdered manganese, shaking the mixture after each addition. Then insert into the neck of the flask a glass or leaden tube, bent into the proper form for conveying the gas into receivers inverted over water; and having made the joint good, by bladder tied firmly down with string, and covered with a little moistened linen or flax, to prevent the bladder from being burned, apply the heat of a spirit, or Argand's oil lamp. The flask should occasionally be agitated, to keep the manganese mixed with the acid, which a little use will enable the operator to do, without removing the orifice of the conducting tube from beneath the water. From 10 to 20 cubic inches of the first portion of gas that comes over may be rejected, and the remainder kept for use, washing it, if required for delicate purposes, with liquid potash or lime water. From the above quantity of materials, 170 or 180 cubic inches of oxygen, containing only about 4 per cent. of impurities, may be obtained. This, for the reason already given, is less than the theoretical proportion, (*viz.* 24 cubic inches from 44 grains,) though more sulphuric acid may have been used than is required to convert the peroxide into protosulphate of manganese. The residuum is generally so hard, that the flask is unavoidably sacrificed.

3. The red oxide of lead (the common red lead used by painters,) similarly heated either with or without an equal weight of concentrated sulphuric acid, gives oxygen gas of considerable purity.

4. It may be obtained from various other oxides, as will be hereafter mentioned.

5. From nitrate of potassa (common saltpetre) made red-hot in a gun-barrel, or in an earthen retort; but, as thus obtained, it is far from being pure.

6. From chlorate of potassa heated in a small coated glass retort, over an Argand's lamp. The oxygen gas thus produced, is much purer than that obtained in any other mode, especially the last portions, which should be kept separate. In a quantity of oxygen gas prepared with great care from this salt, Humboldt and Gay Lussac could discover only four parts of impurity in 1000. It will be found, also, to be much less contaminated with common air, if the salt be heated in a small mattrass, which is best when of green glass. The chlorate of potassa may be introduced while the tube is straight, which allows us to use one of very small diameter. After this it may be bent by a spirit lamp, as represented in the annexed cut. From 100 grs. of the chlorate, between 110 and 115 cubic inches of gas may be expected. (See the article on Chlorate of Potassa.)



All oxides, after having yielded oxygen gas, are found considerably diminished in weight; and calculating each cubic inch of gas to be equal to one third of a grain, the loss of weight by the oxides will be found equivalent to that of the gas generated.

II. Oxygen gas has the following properties:

1. It is so sparingly absorbed by water,[*] that, when agitated in contact with that fluid, no perceptible diminution takes place. When, however, the water has been carefully purged of air, it will be found that 100 cubic inches are capable of absorbing about four cubic inches of oxygen gas.

2. *It is rather heavier than common air.* Messrs. Allen and Pepys determined 100 cubic inches to weigh 33.82 grains, the barometer being 30, and the thermometer 60; from whence its specific gravity may be deduced to be 1.1088. By Biot and Arago its specific gravity is stated to be 1.10359; by Thenard 1.1025; by Berzelius and Dulong 1.1026; and by Dr. Thomson 1.1111. Reckoning 100 cubic inches of atmospheric air to weigh 30.5 grains, 100 cubic inches of oxygen should weigh, according to Berzelius, 33.629 grains, or according to Dr. Thomson 33.888 grains.

3. It *refracts the rays of light* less than any other gas.

4. When suddenly and strongly compressed, not only heat is evolved, but the *gas becomes luminous*, a property belonging to no other simple gas except chlorine.

5. *All combustible bodies burn in oxygen gas with greatly increased splendour.*

(*a*) A lighted wax taper, fixed to an iron wire, and plunged into a vessel of this gas, burns with great brilliancy, pl. iv. fig. 38. If the taper be blown out, and let down into a vessel of the gas, while the snuff remains red-hot, it instantly rekindles, with a slight explosion.

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[*] In this as in several other instances, where a gas is said not to be absorbed by water, the assertion is not to be taken strictly, but merely as implying that only a minute and difficultly appreciable portion is absorbed. The precise proportion of each gas absorbed by water is stated in chap. vii. sec. i.

(*b*) A red-hot bit of charcoal, fastened to a copper wire, and immersed in the gas, burns vividly, and throws out beautiful sparks. Charcoal made of bark, is best adapted to this purpose.

(*c*) The light of phosphorus, burnt in this gas, is the brightest that can be in any mode produced; if we except, perhaps, the ignition of charcoal by Voltaic electricity. Let the phosphorus be placed in a small hemispherical tin cup, which may be raised by means of the wire stand, plàte ii. fig. 25, two or three inches above the surface of water contained in a broad shallow dish. Fill a tall bell-shaped receiver, having an open neck at the top, to which a stopper is ground, with oxygen gas; and, as it stands inverted in water, press a circular piece of pasteboard, rather exceeding the jar in diameter, over its mouth. Cover the phosphorus and the stand instantly with the jar of oxygen gas, retaining the pasteboard in its place, till the jar is immediately over the cup. When this has been skilfully managed, a very small portion only of the oxygen gas will escape. The stopper may now be removed for a few seconds, when the water will rise to the same level within as without the jar, and the phosphorus may be kindled by a heated copper wire.

(*d*) Substitute, for the phosphorus in experiment c, a small ball formed of turnings of zinc, in which about a grain of phosphorus is to be enclosed; and set fire to the phosphorus as before. The zinc will be inflamed, and will burn with a beautiful white light. A similar experiment may be made with metallic arsenic, which may be moistened with spirit of turpentine. The filings of various metals may also be inflamed, by placing them in a small cavity, formed in a piece of charcoal, igniting the charcoal, and blowing, on the part containing the metal, a stream of oxygen gas from a bladder.

(*e*) Procure some thin harpsicord wire, or soft iron wire, and twist it round a slender rod of iron or glass, so as to coil it up in a spiral form. Then withdraw the rod, and tie a little thread or flax round one end of the wire, for about one-20th of an inch; which end is to be dipped into melted sulphur. The other end of the wire is to be fixed into a cork; so that the spiral may hang vertically (fig. 39.) Fill, also, with oxygen gas, a bottle capable of holding about a quart, and set it with its mouth upward. Then light the sulphur, and introduce the wire into the bottle of gas, suspending it by the cork. The iron will burn with a most brilliant light, throwing out a number of sparks, which are projected against the sides or fall to the bottom of the bottle, melt and penetrate the glass, and frequently break it. This accident, however, may sometimes be prevented by pouring sand into the bottle, so as to lie about half an inch deep on the bottom (see pl. iv. fig. 39.) According to Mr. Accum, a thick piece of iron or steel, such as a file, if made sharp-pointed, may be burnt in oxygen gas. A small bit of wood is to be stuck upon its extremity, and set on fire, previously to immersion in the gas.

(*f*) A little of Homberg's pyrophorus, a substance to be hereafter described, when poured into a bottle full of this gas, immediately flashes like inflamed gunpowder.

From this detail of its properties, it appears, that oxygen gas is eminently a *supporter of combustion.* It was long, indeed, supposed to be the only supporter, and the presence of oxygen was imagined to be absolutely essential to combustion. It will appear, however, in the sequel, that other simple bodies capable of existing in an aërial form, are equally entitled to rank as supporters of combustion. Among these are chlorine, iodine, bromine, and possibly fluorine. But they do not all support the combustion of the same substances; charcoal, for example, does not burn in chlorine, and potassium is the only body that is known to burn in the vapour of iodine.

III. *During every combustion in oxygen gas, the gas suffers a considerable diminution.*—To exhibit this on a large scale, and in a manner perfectly free from all sources of error, would require such an apparatus, as few but adepts in chemistry are likely to possess. The apparatus, adapted to this purpose and employed by Lavoisier in the combustion of phosphorus, is described in the 5th chapter of his Elements of Chemistry; and is well adapted to show the absorption of oxygen gas. But persons, who are in possession of a mercurial trough, even of small size, may satisfy themselves of the fact, by an easy experiment. Invert a tube about six inches long, and half an inch diameter, filled with dry mercury, in the trough. About one half of the mercury may then be displaced from the tube by dry oxygen gas, and a small bit of phosphorus, not exceeding a grain, deprived of moisture by blotting-paper, may then be let up to the gas. The phosphorus may be kindled, by bringing the flame of a spirit-lamp, gradually and cautiously, near that part of the outside of the tube, when held at a proper angle, which is contiguous to the phosphorus. It will burn brilliantly, and will continue to do so, till the oxygen has almost entirely disappeared, and the mercury has taken place of the gas. The mercury may then be poured out, and the tube reserved for an examination of its contents. A small quantity of water, employed to wash it out, will be found to have become sour to the taste, and to have acquired the property of reddening litmus paper, showing the formation of phosphoric acid.

IV. *During the combustion of bodies in oxygen gas, a large quantity of caloric is liberated.*—Lavoisier has endeavoured to prove (Elements of Chemistry, chap. ix.) that a given weight of oxygen abandons very different quantities of heat, when combined with different inflammable bodies. For example, the caloric disengaged from 1 pound of oxygen gas, during the combustion of its equivalent of phosphorus, he estimates to be sufficient to melt between 66 and 67 pounds of ice; of charcoal, between 37 and 38 pounds; and of hydrogen, 52 pounds of ice. These results agree generally with the later ones of Despretz, who finds that hydrogen is the combustible which develops least heat for the same quantity of oxygen absorbed; and that the metals disengage most. Charcoal, which does not change the volume of oxygen gas by its combustion, gives a quantity of heat equivalent to 3-5ths of what is evolved by the metals (Ann. de Ch. et Phys. xxxvii. 180.) There can be little doubt that the heat, evolved in these combustions, as well as the light, has its origin partly from the oxygen gas, and partly from the combustible body; but the precise quantity due to each cannot be determined; nor can we arrive at any thing more than the relative quantities of heat which are evolved by different bodies during the decomposition of a given volume of oxygen gas; in other words, at a comparison of the heat evolved with the oxygen spent. It must be understood, however, that the transition of oxygen from the gaseous to a more dense state is not essential to the phenomena of combustion; for besides that we have several examples of true combustion where oxygen is not at all concerned, as in those effected by chlorine, the principle is still more limited by a variety of cases, to be afterwards mentioned, which show that active and vivid combustion is sometimes attended, not with a condensation of the bodies that combine, but on the contrary, with a great enlargement of their united volumes; and, what is still more remarkable, that in some instances, the new compounds formed by combustion, have as great a capacity for heat as their constituent principles. (See Petit and Dulong's Memoir, Ann. de Ch. et de Phys. x. 395.) In a variety of instances, also, gaseous substances, when mingled together, pass to the fluid and even to the solid state, without any appearances of combustion, ammonia and muriatic acid for instance.

V. *All bodies, by combustion in oxygen gas, acquire an addition to their weight; and the increase is in proportion to the quantity of gas absorbed,* viz., *about one-third of a grain for every cubic inch of gas.*—To prove this by experiment, requires also a complicated apparatus. But sufficient evidence of the general fact of an increase of weight may be obtained by the following very simple experiment. Fill the bowl of a tobacco-pipe with iron wire coiled spirally, and of known weight; let the end of the pipe be slipped into a brass tube, which is screwed to a bladder filled with oxygen gas, and unite the two by slips of moistened bladder, bound down by pack-thread. Then heat the bowl of the pipe, and its contents, to redness in the fire, and force through it a stream of oxygen gas from the bladder. The iron wire will burn; will be rapidly oxidized; and will be found, when weighed, to be considerably heavier than before.

VI. The substances, capable of uniting with oxygen, afford one or other of the following products: 1st, *an acid;* 2dly, *an alkali or earth;* or 3dly, *an oxide.* It is not easy to give precise definitions of these three classes of compounds. Of the acids, for instance, there are some which, though entitled to that epithet by their general qualities of chemical combination, are not sour to the taste; and others which do not redden vegetable blue colours. Nor is oxygen an element essential to the acidity of a compound, for some bodies are rendered acid by union with chlorine, and others by combination with hydrogen. The theory, therefore, which considered oxygen as the essential principle of acidity, and in conformity to which its present name was assigned to it, (from ὀξὺς, *acid*, and γεινομαι, *to generate*,) can no longer be considered as correct.*

Alkalis and earths are chiefly distinguished by acting as *bases*, with which the acids combine, with the loss generally of the separate characters both of acid and base. The alkalis are soluble in water, and change some vegetable blues to green; and the earths are either not soluble at all, or sparingly soluble in that fluid; but in the quality of insolubility they agree with many of the third class of compounds, *viz.*, oxides, especially with those derived from the metals, which also serve as bases to the acids. Of the phenomena of metallic oxidation, and the general principles deduced from them, a full account will be given in the chapter on METALS.

In many instances, a combustible body, which affords an acid when united with a certain quantity of oxygen, gives an *oxide* when combined with a less quantity; and the acid may be brought back to the state of an oxide by separating part of its oxygen. We have examples, also, furnished chiefly by a few of the metals, in which the same body, combined with a small proportion of oxygen, gives an oxide that is capable of acting as a base with acids, and of composing salts; and again, the same metal united with more oxygen, yields an acid which is susceptible, with alkalis and earths, of forming saline compounds.

VII. *Oxygen gas supports, eminently, animal life.*—It will be found that a mouse, a bird, or other small animal, will live four or five times longer in a vessel of oxygen gas, than another animal, of the same kind and size, will live in a jar of atmospherical air of the same dimensions.

VIII. *This effect seems connected with the absorption of oxygen by the blood.*—Pass up a little dark-coloured blood into a jar partly filled with oxygen gas, and standing over mercury. The gas will be in part absorbed, and the colour of the blood will be changed to a bright and florid red. This change to red may be shown, by putting a little blood into a common vial filled with oxygen gas, and shaking it in contact with the gas.

SECTION II.

Of Chlorine.

CHLORINE was discovered by Scheele in the year 1774, and, under the name of *dephlogisticated marine acid*, was first described by him in an excellent Essay on Manganese. It was afterwards termed in the French nomenclature *oxygenated or oxygenized muriatic*

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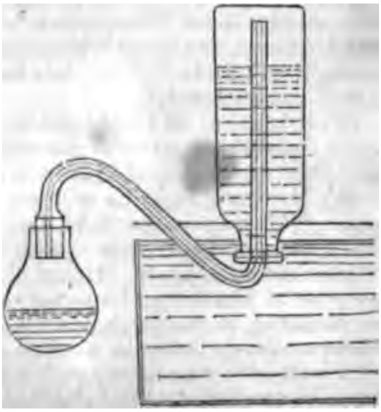
* Lavoisier, in framing the doctrine of acidification, has been charged with too hasty a generalization. This charge is unjust; for he expressly says, "But when, from particular facts, the general induction is made, that *oxygen is a principle common to all acids*, the consequence is founded on analogy, and here it is that theory commences." (Kirwan on Phlogiston, p. 20.)

acid, and by Dr. Pearson *oxymuriatic acid*, a name generally received in this country, till superseded by that which it now almost universally bears. The simplest state, in which we are able to examine its properties, is that of a gas.

I. This gas may be formed by either of the following processes:

Process 1. By the action of liquid muriatic acid upon peroxide of manganese. The proportions, supposing the substances to be pure, are 74 parts = 2 atoms of real acid, and 44 parts = 1 atom of peroxide of manganese, which last is equivalent to 1 atom (36) of protoxide + 1 atom of oxygen. Supposing grains to be taken, 37 grains of the acid are decomposed into 36 grs. of chlorine (= about 27½ cubic in.), which may be collected in the gaseous state, and 1 gr. of hydrogen, which takes 8 grs. of oxygen, from the peroxide, and forms 9 of water. The atom of undecomposed acid (37) unites with the atom of protoxide of manganese (36) to form 73 of protomuriate. In practice, muriatic acid of the specific gravity 1.130, or thereabouts, will be found best adapted to afford chlorine gas, without risk of the materials being carried over by effervescence. Of such an acid, one part of the peroxide, supposing it pure, will require rather more than ten parts; but three or four of these may be abated for the impurity of the manganese. If acid of this density be not at hand, it may be employed of any other sp. gr., calculating by the Table at the end of the second volume, how much must be taken as the equivalent of 74 parts of real muriatic acid.

Process 2. Grind together in a mortar eight ounces of chloride of sodium (common salt) with three ounces of finely-powdered peroxide of manganese; put them into a stoppered retort, and pour on them four ounces of sulphuric acid, which have been diluted previously with four ounces of water, and suffered to cool after dilution. Or the theoretical proportions may be employed, *viz.*, 60 parts of chloride of sodium, 44 parts of oxide of manganese, sulphuric acid (s. g. 1848) 98 parts, diluted with an equal weight of water. On applying a gentle heat, which, in both processes, is best obtained by a small water-bath gradually raised to 212° Fahr., gas will be produced. But as the gas is absorbed by contact with cold water, though not rapidly, it should be received, when it is intended to be kept, in bottles filled with, and inverted in, water of the temperature of 80° or 90° Fahr. and provided with accurately-ground stoppers. It will be found also much to diminish the loss of gas by absorption, if it be made to issue from a gas bottle, the tube of which is sufficiently long to reach



nearly to the bottom of the inverted receiving bottle; for the gas is thus prevented from passing in bubbles through a long column of water. (See the annexed cut.) The stopper must be introduced under water, while the receiving bottle remains quite full of the gas, so that no water may be left in the bottle, along with the gas.

II. Chlorine gas has the following properties:

(*a*) It has a yellowish green colour; and this property has suggested the name *chlorine*. (From χλωρος, green.)

(*b*) It has a pungent and suffocating smell. In experiments on this gas, great care should be taken that it does not escape, in any considerable quantity, into the apartment; for its action on the lungs is extremely painful and injurious. When this accident has happened, the best remedy is to breathe the vapour of solution of ammonia.

(*c*) It is heavier than common air (taking the statement of Gay Lussac) in the proportion of 2.470 to 1.000 by experiment, or 2.4216 by calculation; and 100 cubic inches should, therefore, weigh 75.33 grains. Sir H. Davy found them to weigh between 76 and 77 grains, at a mean temperature and pressure, the latter of which numbers would make its specific gravity 2.5082. Dr. Thomson fixes its sp. gr. at 2.500, which, taking his statement of the sp. gr. of hydrogen to be correct, *viz.*, 0.0694, would make it 36 times the weight of hydrogen. He has shown, also, that Gay Lussac's result, if corrected for the presence of moisture, comes as nearly as can be expected to the same number, *viz.*, to 2.507. (First Prin. of Chem. i. 79.)

(*d*) When chlorine gas is *suddenly* and considerably condensed by mechanical pressure, not only heat is evolved, as from all other gases, but light also; a property peculiar to this gas and to oxygen, at least among the simple gases.

(*e*) It is not changed by being transmitted through ignited porcelain tubes, nor by a succession of electrical discharges through it; a fact strongly confirming the opinion of its being a simple body.

(*f*) When a burning taper is introduced into a vessel of chlorine gas, the flame becomes red, a dense smoke arises, and the taper is soon extinguished. Phosphorus, however, takes fire the moment it is introduced, and burns vehemently; and many of the metals, when brought in a finely-divided state into contact with the gas, exhibit a brilliant combustion.

(*g*) It is not at all acted upon by oxygen gas, but with hydrogen gas a remarkable series of phenomena takes place, which will be described in treating of hydrogen.

(*h*) Chlorine gas, in its ordinary state, destroys all vegetable colours. This may be shown by passing, into the gas confined by water, a piece of paper stained with litmus, the colour of which will immediately disappear. Hence the application of this gas to the purpose of bleaching; its power of effecting which may be shown by confining, in the gas, a pattern of unbleached calico, which has been previously boiled in a weak solution of caustic potassa, and then washed in water, but not dried. Chlorine gas, however, which has been carefully dried by solid chloride of calcium, and into which perfectly dry litmus paper is introduced, produces no change of colour in the litmus, a proof that its bleaching power depends on the presence and decomposition of water.

(i) This gas is absorbed by water; slowly, if allowed to stand over it quiescent, but rapidly when agitated.

1. The best method of effecting the impregnation of water with this gas, is by means of a Woulfe's apparatus, the bottles of which should be surrounded by cold water. The quantity of the gas, which water is capable of absorbing, appears, from the concurrent testimony of Davy and Dalton, to be twice its bulk. The former has remarked that water, apparently saturated with chlorine by agitation with it in a narrow vessel, takes up a further portion of the gas when exposed with a broad surface.

2. The watery solution, if perfectly free from common muriatic acid, has not the taste of an acid, but an astringent one. Its purity from muriatic acid may be ascertained by a solution of nitrate of mercury, which is not precipitated by pure chlorine.

3. The watery solution has the colour and peculiar smell of the gas, and has a similar property of discharging vegetable colours. Hence it may be employed in bleaching.

4. When the watery solution of chlorine is exposed to a temperature only a little above that of freezing water, the gas, which is combined with it, separates in the form of a liquid, heavier than water.

5. Chlorine is not altered by the temperature of boiling water; for its solution may be raised in distillation, and again condensed without change.

6. When the solution of chlorine in water is exposed to the direct rays of the sun, oxygen gas is obtained, and the chlorine, attracting hydrogen from the water, passes to the state of muriatic acid. Placed in the current of the electric fluid, the chlorine, and the oxygen of the water, arrange themselves at the positive, and the hydrogen at the negative pole.

(k) By a temperature of — 40° Fahr. chlorine is reduced into a liquid form, and is condensed on the sides of the vessel. But if the gas be previously dried by exposure to fused chloride of calcium, it bears the most intense artificial cold without condensation. (Davy, Phil. Trans. 1811. p. 30.)

Hydrate of Chlorine.

When a receiver, filled with this gas, not artificially dried, is surrounded by snow, or pounded ice, a crystalline solid of a yellowish colour is formed on its inner surface, resembling, in its ramifications, the ice which is deposited on the surface of windows during a frosty night. By a moderate increase of heat, such as to 50° Fahrenheit, this solid melts into a yellowish oily liquid, which, on a further elevation of temperature, passes to the state of a gas.

The crystals may be best obtained by introducing, into a clean bottle of the gas, a little water, but not enough to convert the whole into hydrate, and then exposing the bottle for a few days to a temperature at or below freezing, in a dark place. A solid *hydrate of chlorine* is formed, which, in a day or two, sublimes and shoots into delicate prismatic needles, extending from half an inch to two inches into the atmosphere of the bottle. They appear to have a specific gravity rather exceeding 1.2.

When these crystals are put into alcohol, they increase its temperature 8° or 10°, a rapid action takes place, and much ether and muriatic acid are formed, with a small proportion of a triple compound of chlorine, hydrogen, and carbon. They decompose the solutions of ammoniacal salts, from which they liberate nitrogen gas. At the same time, muriatic acid and chloride of nitrogen are formed.

By precipitating with nitrate of silver a known weight of the crystals, made as dry as possible and then dissolved in water, Mr. Faraday, to whom we owe these interesting facts, obtained proportions of chloride of silver indicating the crystallized hydrate to consist of

Chlorine - - - - - - - - -	27.7
Water - - - - - - - - - -	72.3
	100.

This nearly accords with ten atoms of water to one of chlorine, giving for the equivalent of the hydrate 90 + 36 = 126.

A portion of the solid and dried hydrate was put into a small bent tube, which was hermetically sealed. On being heated to 100°, a yellow vapour formed, which condensed in the cool part of the tube into two fluid substances; the one, about three-fourths of the whole, was of a faint yellow colour, having very much the appearance of water; the remaining fourth was a heavy bright yellow fluid, lying at the bottom of the former, without any apparent tendency to mix with it. These two fluids it was found easy to separate from each other by careful distillation, and when allowed to cool, neither of them solidified at temperatures above 34°, and the yellow portion not even at 0°. At temperatures below 60°, the two fluids united, and formed the same solid as that first submitted to experiment. If, when the fluids were separated, the tube was cut in the middle, the parts flew forcibly asunder, and the whole of the yellow portion disappeared, emitting a strong smell of chlorine; but the pale fluid remained, and proved to be nothing more than a weak solution of chlorine in water, with a little muriatic acid, probably an impurity of the gas. When the portion of the tube, containing the yellow liquid, was broken under a jar of water, chlorine immediately rose into it in a gaseous state.

In these experiments, hydrate of chlorine had been separated by heat into water still impregnated with a little chlorine, and pure chlorine which, by the mere pressure of its own abundant vapour, had assumed the liquid form; and it was found that chlorine gas artificially dried, might be liquefied by strong mechanical pressure. It was perfectly limpid and excessively volatile at common temperatures. It continued fluid at 0° F.; and when the tube was cut, a part flew off, leaving the rest so cooled by evaporation, that it remained a liquid. The specific gravity of this liquid, as nearly as it could be approximated, was found to be 1.33. (Phil. Trans. 1823.)

Chlorine is susceptible of combination with various other bodies, and the compounds possess, in many instances, remarkable properties. At present we shall describe those only which result from the union of chlorine with oxygen.

ART. 1.—*Protoxide of Chlorine, or Euchlorine.*

When chlorate of potassa (a salt which will be afterwards described) is distilled, at a gentle heat, with muriatic acid diluted with an equal volume of water, a gas may be collected over mercury, which is found to differ essentially from chlorine. For producing the gas, Professor Silliman prefers placing the materials in a small glass flask, furnished with a tube bent twice at right angles, and passing to the bottom of any clean dry phial, flask, or tube, rather deep and with a narrow neck. A gentle heat, applied beneath the flask, soon disengages the euchlorine gas, which, by its great weight, displaces the common air from the recipient, and takes its place. By using tongs properly curved, so as to embrace the phials or tubes filled with the gas, the operator may perform all the necessary experiments, without danger of causing an explosion by the warmth of the hands. (Amer. Journ. vi. 165.) The colour of the gas has a dense tint of brilliant yellow green; and its smell resembles that of burnt sugar, mixed with the peculiar smell of chlorine. Water takes up eight or ten times its volume, and acquires an orange tint. It has been called by its discoverer, Sir H. Davy, *Euchloric gas*, or simply *Euchlorine.* (Phil. Trans. 1811.) Gay Lussac has proposed for it the name of *Oxide of Chlorine;* but it may, with more propriety, be called *Protoxide of Chlorine.*

By producing euchlorine in strong glass tubes hermetically sealed, the unoccupied end of the tube being cooled to 0° F., Mr. Faraday obtained it in the form of a very transparent liquid, of a deep yellow colour, which was suddenly and violently converted into gas on relieving it from pressure. (Phil. Trans. 1823, p. 194.)

Euchlorine gas explodes by a gentle heat, applied to the vessel which contains it, and five parts in volume become six, consisting of a mixture of oxygen and chlorine gases, in such proportions that euchlorine must be composed of two in volume of chlorine and one of oxygen, the latter being condensed into half its bulk, or by weight of

Chlorine - - - -	36
Oxygen - - - -	8
	44

These proportions indicate that euchlorine is constituted of one atom of chlorine = 36, + one atom of oxygen = 8, and hence its atom must weigh 44.

When detonated with twice its volume of hydrogen gas, there is a condensation of more than two-thirds of the mixture, and liquid muriatic acid is formed.

Mercury has no action on euchlorine at common temperatures. Antimony and copper burn it, if introduced previously heated. Sulphur and phosphorus decompose it; and charcoal already ignited burns in it with a dull red light. Nitrous gas condenses it with red fumes.

Euchlorine destroys vegetable colours; but it first gives the blue a tint of red.

In most cases of vivid combustion, there is a condensation of the bodies which unite; but, in the decomposition of euchlorine by heat, we have the remarkable phenomenon of an explosion, accompanied with heat and light, and yet with an expansion of the elements, which are separated from each other.

Art. 2.—*Peroxide of Chlorine.*

Another compound of chlorine and oxygen, containing a larger proportion than euchlorine of the latter element, was discovered by Sir H. Davy, (Phil. Trans. 1815, part 2,) and has since been made the subject of a series of experiments by Count Stadion of Vienna. (Thomson's Annals, ix. 22.) As it exhibits no acid properties, it may be called *peroxide of chlorine*, a name, it appears to me, preferable to that of *deutoxide* or *tritoxide*, which have also been applied to it, because intermediate compounds will probably be discovered between this oxide and the protoxide already described.

To procure it, 50 or 60 grains of the powdered chlorate of potassa are to be mixed with a small quantity of concentrated sulphuric acid. When thoroughly incorporated, a solid mass will result of a bright orange colour. This is to be introduced into a small retort of glass, which is to be exposed to the heat of water gradually warmed, but prevented from attaining the boiling point by an admixture of spirit of wine. Count Stadion obtained it by pouring, over a small quantity of chlorate of potassa fused in a retort, some concentrated sulphuric acid, and exposing the retort to water for three hours, gradually raising its temperature to 212°. The gas may be received over mercury, on which it has no action at common temperatures.

It has a lively yellow colour, much more brilliant than that of euchlorine; is much more rapidly absorbed by water; and has a peculiar aromatic smell, not mixed with any smell of chlorine. According to Davy, it destroys vegetable blue colours, without first reddening them; but Count Stadion asserts that it does not change blue paper. When heated to about the temperature of 212° Fahr., or, according to Count Stadion, to between 112° and 114°, it explodes with more violence, and a greater expansion of volume, than euchlorine, producing much light. After explosion over mercury, from 2.7 to 2.9 volumes appear, for every two of gas decomposed; and, of these, two, as Count Stadion also admits, are oxygen, and the rest chlorine. A little chlorine is absorbed, however, by the mercury, and it is reasonable, Sir H. Davy thinks, to conclude that the deep yellow gas is, in reality, composed of two in volume of oxygen, and one of chlorine, condensed into two volumes. If this be correct, the gas must be a *quadroxide*, consisting of one atom of chlorine 36, and four atoms of oxygen 32, and its atom will weigh 68. But if, as Count Stadion asserts, it gives two volumes of chlorine and three of oxygen, it should consist of one atom of chlorine and only three of oxygen. It is doubtful, indeed, whether the gases, obtained by these philosophers, really constitute two distinct species, or are mixtures of euchlorine and the peroxide of chlorine in various proportions.

It is not decomposed, at common temperatures, by any combustible body, except phosphorus, which occasions an explosion when introduced into it, and burns, in the liberated gases, with great brilliancy.

Its saturated solution in water, which contains seven volumes of gas, is of a deep yellow colour. It does not taste sour, but extremely astringent and corroding; and it leaves on the tongue a disagreeable and lasting impression. The solution may be kept in the dark unchanged, but, when exposed to the sun's rays, it is decomposed, and chlorine and chloric acid are obtained.

ART. 3.—*Chloric Acid.*

A third compound of chlorine and oxygen was pointed out by Mr. Chenevix, some time before it was obtained in a separate form, as existing in the class of salts called by him hyper-oxymuriates, now termed *chlorates*. For the method of exhibiting it in a distinct state, we are indebted to Vauquelin (Ann. de Chim. xcv. 102) and Gay Lussac (Ibid. xci. 111). The following is the process: To a solution of pure chlorate of baryta (the mode of preparing which will be described chap. ix. sect. 5,) add by degrees dilute sulphuric acid, as long as it occasions any precipitation. This separates the baryta, and leaves the chloric acid combined with water only. It is important to add no more sulphuric acid than is barely sufficient; for the slightest excess renders the chloric acid impure. If the right quantity has been used, the liquid obtained should remain perfectly transparent, when, taking two separate portions of it, we add to the one dilute sulphuric acid, and to the other chlorate of baryta. If either of these agents occasions a precipitate, we must add it by degrees till the effect ceases. The clear liquid is then to be decanted by a syphon, and reserved for use. It is a solution of chloric acid in water; and has the following properties.

1. It is free from colour; its taste is acid and astringent; and its smell, when concentrated and a little heated, is moderately pungent.

2. It reddens the infusion of litmus. Paper stained with litmus, though it does not immediately lose its colour, yet is deprived of it in a day or two if left in the liquid; or more rapidly if taken out of the liquid and exposed to the air, in consequence of the solution becoming more concentrated.

3. It does not precipitate either silver, mercury, or lead, from nitric acid.

4. It is volatilized by heat, but not without a partial decomposition into chlorine and oxygen. Hence it afterwards precipitates the nitrate of silver.

5. Muriatic acid decomposes it, and both acids, if mixed in just proportions, are changed entirely into chlorine.

6. Chloric acid is decomposed, also, by sulphuretted hydrogen and by sulphurous acid. In the first case, chlorine and sulphur are separated, and water is formed. In the second, sulphuric acid is formed, and chlorine set at liberty. None of the acids, which are saturated with oxygen, have any action on chloric acid.

7. All the metals that are capable of decomposing water, decompose also the chloric acid, and afford compounds of chlorine with a metallic oxide.

According to the experiments of Vauquelin, chloric acid is composed of

Chlorine	35	36
Oxygen	65	66.85
	100	

This determination differs materially from that of Gay Lussac, according to whom 32.304 oxygen convert 28.924 chlorine into chloric acid, and hence it should be composed of

Chlorine	47.3	36
Oxygen	52.7	40.21
	100.	

The result obtained by Gay Lussac is by much the more probable of the two. It would make the chloric acid consist of one atom of chlorine + 5 atoms of oxygen (together = 76), while Vauquelin's numbers indicate no less than 8 atoms of oxygen.

It is proper, however, to add that the existence of a simple combination of chlorine and oxygen has been disputed by Sir H. Davy, who considers the liquid obtained by Gay Lussac as constituted of two proportions (atoms) of hydrogen, one of chlorine, and six of oxygen. To this the latter philosopher has replied, that the hydrogen is not an element of the acid itself, but of water, with which the acid is united, as is the case with liquid sulphuric and nitric acids. The reader who takes an interest in this controversy is referred to the first volume of Annales de Chimie et de Physique, or to the Quarterly Journal of Science. The argument for the existence of hydrogen in certain acids, as an essential and acidifying principle, and not as a constituent of water, has been ably supported by Dr. Murray, in the Edinburgh Philosophical Transactions.

We are not acquainted with any compound of chlorine and oxygen that can be entitled to the name of *chlorous* acid. Berzelius is induced, chiefly by analogical arguments, to believe in the existence of such an acid, and that it is the first in order of the products which are formed, when we transmit a current of chlorine through caustic alkaline liquors. At present, however, it is purely hypothetical. (See Ann. de Ch., June 1828.)

ART. 4.—*Perchloric Acid.*

In obtaining peroxide of chlorine by Sir H. Davy's or by Count Stadion's process, a peculiar salt is formed, which was first noticed by the latter philosopher. It is mixed with bisulphate of potash, which may be separated by a second crystallization, and the peculiar salt then appears in octohedral crystals. It requires 55 times its weight of water at 60° for solution, but dissolves freely in boiling water. In alcohol it is quite insoluble. When distilled with an equal weight of sulphuric acid, at a temperature of 280° Fahr., it is decomposed; and an acid (of whose properties, however, we have not a distinct account) may be distilled over. When the salt is distilled alone at 412°, it is converted into chloride of potassium and oxygen gas, in the following proportions. One hundred parts by weight afford

Chloride of potassium - -	54.08	containing	28.49 potassium 25.59 chlorine
Oxygen - - - - - - - -	45.92		
	100.		

Hence it appears that 25.59 chlorine are united with 40.21 oxygen (5.71 oxygen being, in the original salt, united with the potassium), which is nearly in the proportion of 36 chlorine to 56 oxygen. Perchloric acid will therefore consist of one atom of chlorine = 36, united with seven atoms of oxygen = 56; and the weight of its atom will be 92.

Recapitulation.

We have thus four well-ascertained compounds of chlorine and oxygen, of which the following table exhibits a concise view.

		Volumes of Chlor. Oxyg.
1st.	Protoxide of chlorine - - - - - - - - -	2 + 1
2d.	Peroxide - - - - - - - - - - - - - -	1 + 2
3d.	Chloric acid - - - - - - - - - - - - -	1 + 2.5
4th.	Perchloric acid - - - - - - - - - - -	1 + 3.5

SECTION III.

Of Iodine, and its Compounds with Oxygen and Chlorine.

Iodine was discovered accidentally, about the beginning of the year 1812, by M. Courtois, a manufacturer of saltpetre at Paris. In the processes for procuring soda from the ashes of sea-weeds, he found his metallic vessels much corroded; and in searching for [illegible] made this discovery. [illegible] new sub[illegible] are given to MM. Des[illegible] and Clement, who read a [illegible] noir upon it, at a [illegible] of the Institute of France, in [illegible] 1813. Its pro[illegible] nbinations have since been [illegible] estigated by Vauque[illegible] (90 An[illegible]. de Chim. 206); by Gay [illegible] ac (91 Ann. de Chim.); by Sir H. Davy (Phil. Trans. 1814); by Gaultier de Claubry and Colin (90, 91, and 93 Ann. de [illegible])

W[illegible] all the soda has been separated by crystallization from a s[illegible] of kelp or barilla, or from the ley of ashes of marine plants, [illegible] rd [illegible] mineral alkali, the r[illegible] ary liquor, in order to pro[illegible] from it, may be mixed w[illegible] peroxide of manganese, and [illegible] l sulphuric acid be [illegible] upon the mixture, in a re[illegible] sned with a receiver. [illegible] ne passes into the receiver, under the form of beautiful violet [illegible] rs, which are condensed in crystalline plates, having the [illegible] of plumbago. To purify it from the redundant acid that c[illegible] s over with it, the iodine may be re-distilled from water, containing a very small quantity of potassa, [illegible] afterwards dried by pressing it between folds of blotting-pa[illegible].* It is now manufactured largely for medicinal use, and may [illegible] purchased at a reasonable price.

General Properties.—Iodine is a solid, at the ordinary temperature of the atmosphere. It is often in scales, resembling those of micaceous iron ore; sometimes in large and brilliant rhomboidal plates; and occasionally in elongated octahedrons.† Its colour is bluish black; its lustre metallic; it is soft and friable, and may easily be rubbed to a fine powder. Its taste is very acrid, though it is sparingly soluble in water, which does not take up above one 7000th part of its weight, and it is poisonous if taken in a large dose. Its specific gravity, at 60° Fahrenheit, is 4.946. When in large octahedral crystals, Dr. Thomson found it to be 3.0884. It is a non-conductor of electricity; and possesses in a high degree the electrical properties of oxygen and chlorine, being determined to the positive pole of a galvanic arrangement. When applied to the skin, it produces a yellow stain, but this disappears as the iodine evaporates.

Iodine is fusible at 225° Fahrenheit, and, under the ordinary pressure of the atmosphere, is volatilized at a temperature somewhere near 350°, forming a vapour 125 times denser than hydrogen. Gay Lussac calculated the specific gravity of this vapour, compared with air, to be 8.678; and Dumas, by actual experiment, finds it to be 8.716 (Ann. de Ch. et de Ph. xxxiii. 348). Its colour is a beautiful violet, and hence its name (from ἰώδης, violaceus.) Its powers as a re-agent, to be noticed in the sequel, are fully described by D'Arcet and Chevreul, in the Ann. de Ch. et de Ph., May 1828.

The atomic weight of iodine may be deduced from the specific gravity of its vapour compared with that of hydrogen, and from the fact that its vapour unites with hydrogen in equal volumes, forming a compound gas in which there is no condensation of elements. In this respect it resembles chlorine. Now, if we consider half a volume of oxygen = 1 atom, we may substitute a volume of chlorine gas for an atom of chlorine, and a volume of vapour of iodine for an atom of iodine. But the specific gravity of vapour of iodine, deduced from Dumas's experiment, is to that of hydrogen gas as 125.66 to 1, and from the analysis of hydriodic acid gas, as 125 to 1. From less direct and more elaborate methods, Dr. Thomson deduces the number representing iodine to be 15.5, oxygen being unity, equivalent to 124 when hydrogen is taken as 1, a number fixed upon by Dr. Prout from other considerations. (First Princ. of Chem. i. 92.) It can be of little consequence at present which number we adopt, the difference between them being so small, that it would require experiments of the greatest nicety to determine which of them is strictly correct.

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* More minute directions for its preparation are given in the Phil. Mag. xl. 57, 141, and 209; and by Dr. Ure, in vol. I.

† Dr. Wollaston has described the form of its crystal in Thomson's Annals, v. 237. See also Journ. of Science, &c. v. 364.

Art. 1.—*Iodine and Oxygen.*

Action of Oxygen.—Iodine undergoes no change by being heated in contact with oxygen gas, or with chlorate of potassa. By the intervention of protoxide of chlorine, however, iodine admits of being combined with oxygen, and it then furnishes a peculiar acid.

Action of Protoxide of Chlorine.—When iodine is exposed to euchlorine, Sir H. Davy has discovered that there is an immediate action; its colour changes to bright orange; and a liquid is formed. (Phil. Trans. 1815, part 2.) By the application of a gentle heat, the orange compound of chlorine and iodine is expelled, and a compound of oxygen and iodine remains. This substance is a white semi-transparent solid, volatile at 456° Fahr.; it has no smell, but a strong astringent sour taste. Its specific gravity is such, that it sinks in sulphuric acid.

When decomposed by heat in a pneumatic apparatus, it is resolved into oxygen gas and pure iodine; and it is therefore termed by Sir H. Davy, *oxyiodine*; by Gay Lussac, *acide iodique anhydre.*[*] Thirteen grains afford 9.25 cubical inches of oxygen gas, = 3.14 grains. Hence it is composed of

Iodine - - -	75.85 - -	100. - -	314.8
Oxygen - - -	24.15 - -	31.84 - -	100.
	100.	131.84	414.8

Iodic acid, therefore, is constituted of

5 atoms of oxygen =	40
1 atom of iodine =	125
And the weight of its atom is	165

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[*] The term *anhydrous*, which will be often used, is derived from a Greek word signifying *without water*.

It presents, then, in its composition, a st[illegible]logy with chloric acid, which is composed of 5 atoms of oxygen and 1 atom of chlorine.

Anhydrous iodic acid is very soluble in water, and is slightly deliquescent.—The solution, called by Gay Lussac *acide iodique*, first reddens and then destroys vegetable blues, and reduces other vegetable colours to a dull yellow. When evaporated sufficiently, it becomes a thick pasty substance, and at length, by a cautiously regulated heat, yields the anhydrous acid unaltered.

When heated in contact with inflammable bodies, or with the more combustible metals, detonations are produced. Its solution in water rapidly corrodes all the metals, and even acts on gold and platinum, but especially on the first.

When its solution is poured into solutions of alkalies, or alkaline earths, or when made to act on their carbonates, triple compounds are formed of oxygen, iodine, and the metallic bases, called by Sir H. Davy, *oxyiodes;* and by Gay Lussac, more properly, *iodates.* With solution of ammonia, it composes iodate of ammonia; and with the soluble salts of baryta and strontia, it precipitates their respective iodates. Forty-eight grains of iodate of potassa, when decomposed by heat, afforded Sir H. Davy 31 cubic inches = 10.5 grains of oxygen gas.

Iodic acid enters into combination with all those fluid or solid acids which it does not decompose. Sulphuric acid, dropped into a saturated solution of it in hot water, precipitates a solid, which on cooling forms rhomboidal crystals of a pale yellow colour. This compound is fusible; and, with a heat properly regulated, may be sublimated unaltered. Hydronitric and hydrophosphoric acids afford analogous compounds. Oxalic and liquid muriatic acids decompose it. All its acid combinations redden vegetable blues; dissolve gold and platinum; and, when added to alkalies or earths, afford common neutral salts, and their respective iodates. In their crystalline state, the compounds of iodic and other acids are most probably hydrates; the acids carrying with them into combination definite proportions of water.

Iodous Acid.—By distilling equal parts of chlorate of potassa and iodine, first triturated together in a porcelain mortar till they form a very fine pulverulent yellow mass, Sig. Sementini obtained a yellow fluid, having an acid and astringent taste, and leaving a burning sensation on the tongue. Pleischl recommends three parts of the chlorate and one of iodine, and that the receiver be kept carefully cooled during the whole operation. The liquid obtained reddens blue vegetable colours, but does not destroy them; is volatile at 112° Fahr., and even at common temperatures, without decomposition; is decomposed when heated with sulphur, but not with detonation like iodic acid; and inflames potassium and phosphorus the instant it is brought into contact with either of them. The proportion of its elements has not been experimentally ascertained. (Quart. Journ. xvii. 381.) Indeed it is asserted by Wöhler, that this fluid is nothing more than a mixture of chloride of iodine with iodine. (Quart. Journ., Oct. 1827.)

A new compound of iodine and oxygen has been pointed out by Mitscherlich, in which the proportion of oxygen is such as to render it analogous to the hyposulphurous acid; and, like that acid, it appears to have so little stability of composition, as to exist only when united with a base. (Ann. de Ch. et de Ph. xxxvii. 84.)

ART. 2.—*Iodine and Chlorine.*

Iodine absorbs less than one-third its weight of chlorine, and forms a peculiar compound, called *chloride*, or *chlorure*, *of iodine*, or *chloriodic acid*. According to Gay Lussac, indeed, two compounds result, the one of a fine orange-yellow colour, containing the largest proportion of chlorine, the other orange-red. Both are solid and crystalline; deliquiate when exposed to the air; are fusible into an orange liquid; and, when more strongly heated, give an orange-coloured gas. The watery solution takes more iodine, and acquires a deeper colour; but, if agitated with chlorine, it is deprived of colour, and when poured, in that state, into solution of potassa, the deflagrating salt is precipitated. From liquid ammonia, the colourless liquid precipitates a white detonating compound; but the coloured solution throws down the darker compound, which detonates on the slightest touch, and is, indeed, identical with that procured by the direct action of iodine on ammonia.

Chloriodic acid precipitates the salts of iron, lead, tin, and copper; probably in the state of iodates.

It has been observed by Gay Lussac, that, in order to convert the whole of a quantity of alkali into the deflagrating salt, without any of the hydriodate (which otherwise is produced in greater proportion than the iodate), it is necessary first to combine the iodine with chlorine; and, after dissolving the compound in water, to saturate it with alkali.

Nature of Iodine.—Iodine, from all that we yet know respecting it, is to be considered as a simple or elementary body, having a very striking analogy with chlorine, which it resembles, 1st, in forming one acid by uniting with hydrogen, and a different acid, by combining with oxygen; 2dly, in its effects on vegetable colours; 3dly, in its affording, with the fixed alkalies, salts which nearly approach in characters to chlorates; and 4thly, in its electrical habitudes. Its discovery, indeed, lends strong support to that theory, which considers chlorine as a simple body, and muriatic acid as a compound of chlorine and hydrogen. In the property of forming an acid, whether it be united with hydrogen or with oxygen, iodine bears, also, an analogy to sulphur; and it is remarked by Gay Lussac of the combinations of chlorine, iodine, and sulphur, with the elements of water, that while the acids, which they respectively form with oxygen, have their elements powerfully combined, those formed with hydrogen have their elements very feebly united. Sulphur has the strongest affinity for oxygen, then iodine, and lastly chlorine. But for hydrogen, chlorine has a stronger attraction than iodine, and iodine than sulphur; whence it appears that the affinity of each of those bodies for oxygen is inversely proportionate to its affinity for hydrogen.

The source of iodine in nature has been investigated by M. Gaultier de Cla[illegible]. (Ann. de Chim. xciii. 75, 118.) His first experiments we[illegible]rected to the analysis of the several varieties of *Fucus*, the co[illegible]tion of which furnishes the [illegible]da of sea-weeds. Before these vegetables are destroyed by combustion, he ascertained that iodine exists in them in the state of *hydriodate of potassa*; and that calcination only destroys the vegetable matters, with which it is combined. As the hydriodate of potassa is a deliquescent salt, it remains in the mother liquor, after separating the carbonate of soda, and most of the other salts, by crystallization. In the course of these experiments, M. de Claubry found that starch is one of the most delicate tests of the presence of iodine, and if added to any liquid containing it, with a few drops of sulphuric acid, iodine is indicated by a blue colour, of greater or less intensity. In this way he detected iodine in the decoction of several varieties of *Fucus*; but he was unable to discover the slightest trace of it in sea-[illegible]ter. The *Fucus Saccharinus* [illegible] it most abundantly; and, in [illegible] to obtain it by the cheapest [illegible] easiest process, he recommends that we should submit this [illegible]*ucus*, dried and reduced to powder, to distillation with sulphuric acid. Vauquelin was the first who discovered iodine in the mineral kingdom: he extracted it from a mineral sent from Mexico under the name of *Virgin silver from Serpentine*, and it is probable that it will be found in other ores of silver, for which metal it has, like chlorine, a very strong affinity. (Ann. de Ch. &c. xxix.) It has since been found in the cadmium accompanying some of the zinc ores of Upper Silesia.

SECTION IV.

Of Bromine.

Bromine was discovered, in August, 1826, by M. Balard, of Montpellier, who has thus added another to the class of electro-negative bodies, and has ably investigated its properties and combinations, on the model of M. Gay Lussac's admirable researches on iodine and cyanogen.

In treating, with chlorine, a ley of the ashes of a fucus containing iodine, M. Balard had often observed that, on adding a solution of *starch*, not only a blue zone appeared, of which iodine formed a part, but, a little above that, a zone of a bright orange-yellow colour. This orange colour was equally produced by treating in the same manner the mother water of the salt-works, and the more distinctly as the liquor was more concentrated. It disappeared, as did also the characteristic smell, by a day or two's exposure to air, and was not again producible by chlorine. Similar effects resulted from adding pure or carbonated alkalies, or any re-agent capable of yielding hydrogen; but, in the latter cases, the colour and smell returned on adding chlorine.

By distilling the yellow solution, a reddish yellow fluid was obtained, of an odour resembling that of euchlorine. It had no acidity, and lost its colour and smell by the action of the same reagents as the original liquor. The water, with which it was largely mixed, having been separated by fused chloride of calcium, the fluid then appeared in the form of drops, of a very deep red colour, very volatile, and filling the whole receiver with vapours resembling those of nitrous acid. With the very minute quantity of liquid thus obtained, M. Balard satisfied himself that it possessed no properties of a chloride of iodine, either chemical or electrical, and he was induced to regard it as a simple body, analogous to chlorine and iodine, but differing from both. To distinguish it, he gave it the name of *Muride*, for which that of *Brome*, from βρωμος, fœtor, was afterwards substituted. This name, when altered to suit the analogy of chlorine, iodine, &c., admits of all the terminations necessary to express the various compounds of the new body with others.

Process. The objection to the first process, already described, for procuring bromine, is the smallness of the quantity obtained, and still more its impurity, for it seemed to be contaminated with carbon and hydrogen, or with a compound analogous to hydrocarburet of chlorine. The following is a better method: Pass, through the mother water of the salt-works, a current of chlorine, not in too great excess, because there is danger of forming a new compound of chlorine and bromine. Pour on this a small quantity of sulphuric ether; and then fill the vessel entirely with the liquid. Agitate them strongly together, and let them stand a short time, in order that the ethereal part may rise to the surface, when it will exhibit a stratum of a fine hyacinthine red. The subjacent liquor is decoloured, and, instead of the sharp irritating smell of bromine, gives only the smell of ether.

The coloured ether (a true ethereal solution of bromine) loses its colour, and its smell also, by agitation with caustic potassa. This absorbs the bromine; and, by successively agitating the yellow mother liquor with ether, and the ether with potassa, we succeed in combining with the alkali all the bromine developed in a great mass of fluid.

By little and little the potassa loses all its alkaline properties, and is transformed into a saline matter soluble in water, and crystallizable in cubes by evaporation. It is from these cubic crystals (hydrobromate of potassa) that M. Balard obtains bromine, by mixing them, when powdered, with pulverized peroxide of manganese, and pouring on this mixture, placed in a retort, sulphuric acid, diluted with half its weight of water. Red vapours are produced, which condense into small drops of bromine. These fall through the water in which the neck of the retort is immersed; but what arrives in vapour dissolves in that fluid. To obtain the bromine pure, the fluid may be distilled from recently fused chloride of calcium.

Properties. Bromine is a reddish black l r. viewed in quantity by reflected light, and of a hyacinth red, when interposed, in a thin stratum, between the light and the eye.

Its very disagreeable odour resembles that of the oxides of chlorine, but is much more intense. Its taste is very powerful.

It attacks organized matters, wood, cork, &c., and tinges the skin yellow. It appears to be an active poison. A single drop introduced into the bill of a bird proved fatal.

Its specific gravity, as near as it could be approached, is 2.966. It is fluid at — 18° cent. (0 F.), but becomes solid at — 4 Fahr. It is exceedingly volatile, and a single drop, put into a glass vessel, instantly fills the vessel with a vapour exactly resembling in colour that of nitrous acid. It boils at + 47° c. (= about 116½° F.) Its vapour is not altered by being transmitted through a red-hot tube.

It does not transmit Voltaic or common electricity, nor is it decomposed by that agent. It is remarkable, however, that water, tinged by adding a few drops of bromine, has its conducting power much increased.

Its vapour is incapable of supporting combustion. A lighted taper, plunged into such an atmosphere, was soon extinguished; but, before going out, it burned some instants, with a flame green at the base, and reddish at the upper part, as is the case in gaseous chlorine.

It is soluble in water, in alcohol, and, above all, in ether; very sparingly so in sulphuric acid. Olive-oil acts upon it slowly. It destroys instantly the colour of tincture of turnsole; and the solution of indigo in sulphuric acid.

These facts point out a considerable resemblance between chlorine, iodine, and bromine. But the analogy is still more striking when we compare the habitudes of the three bodies, and the phenomena and results of their combinations. In this section I shall describe only the action of bromine on electro-negative bodies, a class in which it is itself ranked. In the seventh chapter, its relations to hydrogen will be described: and it will then appear to be a substance which, like chlorine and iodine, is acidified by hydrogen as well as by oxygen.

In the chapter on metals, bromine will be shown, also, to form, with that class of bodies, compounds precisely analogous to metallic chlorides and iodides. With all these striking resemblances, it possesses, at the same time, properties that sufficiently distinguish it both from chlorine and iodine; nor are we yet in possession of any fact that evinces it to be a compound of those two elements.

Art 1.—*Bromine and Oxygen.*

When bromine is agitated with a sufficiently concentrated solution of potassa, two different compounds are formed: one, which will be noticed hereafter in the section on hydrobromic acid; the other, a white crystalline powder, which, when washed and cautiously dried, is fusible at a red heat, and convertible into bromide of potassium, with a disengagement of oxygen gas. From the solution of a similar salt with base of baryta, (see chap. ix. sect. 5,) bromic acid may be obtained by carefully adding sulphuric acid, till it ceases to produce precipitation. By gentle evaporation, the liquid may be brought to a syrupy consistence; but, if the heat be longer continued, the acid is partly volatilized, and partly decomposed into bromine and oxygen gas. The same effects ensue if its concentration be attempted *in vacuo;* hence it appears that water is essential to the existence of this compound of bromine and oxygen.

Bromic acid first reddens litmus paper, and then decolours it. It has scarcely any smell; its taste is acid, but by no means caustic. Nitric acid produces no change in it; but sulphuric acid, when concentrated, develops both oxygen and bromine, probably by abstracting the water, which seems essential to bromic acid. All the hydracids act upon it with considerable energy, their hydrogen uniting with the oxygen of the bromic acid, and their other element with the disengaged bromine.

Bromic acid, added to a solution of silver, throws down a white pulverulent precipitate, not readily soluble in water. It decomposes the salts of lead; but the precipitate is much more soluble than bromide of silver, and also than chloride of lead.

The properties of bromic acid, therefore, approach more nearly to those of the chloric acid than to those of the iodic; and it resembles the former, more especially, in the facility with which it abandons its oxygen.

By converting bromate of potassa into bromide of potassium, the composition of bromic acid was deduced to be

Bromine - - - - -	64.69
Oxygen - - - - - -	35.31
	100.

This would make the weight of the atom of bromine fall a little short of 70; but, from other facts, it would appear to be 75 on the hydrogen scale, or 9.375, oxygen being unity. The bromic acid is probably constituted (analogously to the chloric and iodic acids) of

Bromine - - - -	1 atom - - - -	75
Oxygen - - - -	5 atoms - - - -	40
Weight of its atom	- - - - - - - -	115

ART. 2—*Bromine and Chlorine.*

Bromine unites with chlorine at common temperatures. To obtain this compound, chlorine gas may be transmitted through bromine, and the vapours produced may be condensed by artificial cold.

The *chloride of bromine* is a liquor of a reddish yellow colour, ch less deep than that of bromine itself; of a sharp and penetrating smell, exciting tears; and of a very unpleasant taste. It exceedingly fluid and volatile, and its vapour is of a deep yellow lour, more resembling that of the oxides of chlorine than of lorine itself.

Chloride of bromine dissolves in water, and its solution discharges he colour of litmus paper without reddening it. When added to olutions of potassa, soda, and baryta, hydrochlorates and bromates of those bases are produced; a proof that hydrogen is more powerfully attracted by chlorine than by bromine.

ART. 3.—*Bromine and Iodine.*

Iodine appears susceptible of forming two different compounds with bromine. The first of these is produced by bringing those bodies into contact, in such proportions as to form a solid. This, when heated, gives reddish brown vapours, condensable into small crystals of the same colour, which collect into figures resembling fern-leaves.

When more bromine is added to these crystals, a liquid is obtained resembling hydriodic acid, which contains a great excess of iodine. This liquid is miscible with water, to which it imparts the property of discharging, without reddening, the colour of litmus paper.

Liquid alkalies convert the iodide of bromine into hydrobromates and iodates, showing that hydrogen is more strongly attracted by bromine than by iodine.

SECTION V.

Of Fluorine.

The experiments of Sir H. Davy led him, in 1808, to conclude, chiefly from the action of potassium on silicated fluoric gas, that the fluoric acid is a compound of oxygen with a combustible basis. But as all acids, so constituted, are decomposed by galvanic electricity, their base being determined to the negative, and their oxygen to the positive pole, he has since (Phil. Trans. 1813, part 2, and 1814, part 1) submitted liquid fluoric acid to this test, after having ascertained, by the result of its combination with ammoniacal gas, that in its strongest form it contains no water. Considerable difficulty was experienced in making the necessary exposure of the liquid to electricity, partly in consequence of the dangerous fumes which it emitted, and also in collecting the products. At the negative pole, a gas was evolved, which, from its inflammability, appeared to be hydrogen. The platina wire at the positive pole was rapidly corroded, and covered with a chocolate powder, the properties of which seem not to have been examined.

When fluate of ammonia was treated with potassium, no evidence was obtained of its containing oxygen. Charcoal, also, intensely ignited in fluoric acid gas, gave no carbonic acid. The most simple way of explaining the phenomena appears, therefore, to Sir H. Davy, to be by the supposition, that the fluoric acid, like the muriatic, is composed of hydrogen, and a peculiar base, possessing, like oxygen and chlorine, a negative electrical energy, and hence determined to the positive surface. For this base, which, like chlorine, he believes to combine at once with metals, the name of *fluorine* has been proposed. This substance, from its strong affinities and decomposing agencies, has not yet been exhibited in a separate state; nor have any of the attempts to detach it from its combinations by chlorine or oxygen, (on the presumption that the attraction of one of those bodies for the metals might be superior to that of fluorine,) been hitherto successful.

The number representing the atom of *fluorine*, as deduced from the composition of fluor spar, is 17.1; and fluor spar must be composed of 20 calcium and 17.1 fluorine. On the whole, Sir H. Davy is disposed to estimate the weight of the atom of fluorine at less than half that of chlorine, and to fix it at 33, which is equivalent, on the common hydrogen scale, to 16.5.

ELECTRO-POSITIVE BODIES.

The bodies which are determined to the negative pole of a galvanic arrangement, and whose inherent electrical state may, therefore, be presumed to be positive, have been sometimes termed *simple combustible bodies*. To this title, however, the same objections exist which have been before urged against that of *supporters of combustion* as applied to electro-negative substances; and it may be remarked that one body at least (azote) may with propriety be included among electro-positive bodies, which cannot be considered as combustible, and to which it would otherwise be difficult to assign a place. The electro-positive class comprehends, as we have already observed, all the objects of chemical science, with the exception of the four that have been already described; and, from their great number, it becomes desirable to distribute them into subordinate and less comprehensive divisions. They may be considered, then, either as elementary or compound. The elementary, or those which have not been yet resolved into a more simple state, may be divided into,

I. Those which, by combination with oxygen, chlorine, or hydrogen, are capable of being converted into acids, but which have no metallic properties.

II. Those which either decidedly rank as metals, or are so nearly allied to metals in their general habitudes, as to render it improper to assign to them any other place in a chemical arrangement. In the class of metals will be found a few bodies which yield acids when united with oxygen, and one or two which are even acidified by combination with hydrogen.

A different arrangement has been proposed by Berzelius, in a memoir published in the 32d volume of Ann. de Chim. et de Phys.;

but it is founded on principles not yet recognised by the generality of chemists. It may be sufficient, therefore, to refer those students who are somewhat advanced in chemical philosophy, to the essay itself.

CHAPTER VII.

OF SIMPLE ACIDIFIABLE BODIES (NOT METALLIC), AND THEIR COMBINATIONS WITH OXYGEN, CHLORINE, IODINE, BROMINE, AND FLUORINE.

This subdivision comprehends hydrogen, nitrogen, carbon, boron, phosphorus, sulphur, and selenium, bodies extremely different from each other in their external appearance and physical characters, but still agreeing in the property of being convertible into acids. Of these, hydrogen is acidifiable by chlorine, iodine, bromine, and possibly by fluorine. Nitrogen, carbon, and boron, are acidified by oxygen only; while sulphur and selenium are acidifiable both by hydrogen and oxygen. In selecting the order in which they should be described, I have been governed chiefly by the importance of their compounds, and by the extent of their influence over chemical phenomena. For this reason, I begin with hydrogen, because there are few chemical changes in which water is not concerned, either by acting as a solvent, or by furnishing oxygen or hydrogen, to the bodies with which it is brought into contact.

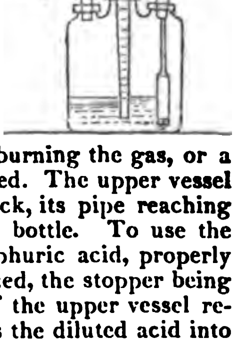
SECTION I.

Of Hydrogen.

The most simple form in which HYDROGEN has hitherto been obtained is in that of a gas, that is, in a state of union with caloric, and perhaps with electricity and light. From this combination we are not able to separate it, except by availing ourselves of the affinity of some other substance, in which case the hydrogen separates from the caloric, and forms, with the body which has been added, a new combination. Of its nature we know but little; but as it has not yet been resolved into any more simple form, it is still arranged among elementary bodies. The date of the discovery of hydrogen gas does not appear to be clearly ascertained; but it seems to have been first attentively examined by Mr. Cavendish. It has been termed *inflammable* or *light inflammable* air, and received its present appellation for a reason which will be stated in the sequel.

I. *To procure hydrogen gas*, let sulphuric acid, previously diluted with five or six times its weight of water, be poured on iron filings or turnings, or on small iron nails; or (which is still better) pour sulphuric acid, diluted with eight parts by weight of water, on zinc,* granulated by pouring it melted into cold water, and contained in a gas bottle or small retort. An effervescence will ensue, and the escaping gas may be collected in the usual manner. According to Mr. Cavendish, one troy ounce (480 grains) of zinc gives 356 oz. measures = about 676 cubic inches, and 1 oz. of iron wire, 412 oz. m. = 782 cubic inches, of hydrogen gas. The proportions of gas which ought to be obtained from given materials, supposing them pure, is easily calculated. It is well known that during the production of gas, the metal is oxidized, not at the expense of the acid, which remains unchanged as to its quantity, but that it derives its oxygen from the water, which is the true source of the evolved hydrogen. Now 28 grains of iron, or 34 of zinc, take from 9 of water 8 grains of oxygen, and 1 grain of hydrogen is liberated, equal in volume to very nearly 47.25 cubic inches. It is, however, advisable to use a quantity of sulphuric acid, rather more than equivalent to the metal employed; for example, to 28 parts of iron, or 34 zinc, more than 49 parts of oil of vitriol, reckoned before dilution, are necessary, in order to obtain the gas with sufficient quickness.

An ingenious apparatus for obtaining hydrogen gas, instantaneously, in a laboratory, is described by Gay Lussac, in the 5th vol. of Ann. de Chim. et de Phys., p. 300; and the annexed cut shows its construction. It consists of a three-necked glass bottle, one of whose openings has a stopper from which is suspended a small cylinder of zinc; or the zinc, instead of being suspended from the top, may be supported from the bottom on a tripod of lead, which is not acted upon by sulphuric acid; though in this case, in consequence of the galvanic action arising from the contact of the zinc and lead, gas ascends also in great abundance from the latter metal. To the opposite aperture is fixed a bent brass tube, furnished with a stop-cock, on which may be screwed either a small jet for burning the gas, or a tube to conduct it wherever it may be required. The upper vessel is of glass, and ground to fit the middle neck, its pipe reaching within a small distance of the bottom of the bottle. To use the apparatus, the lower vessel is filled with sulphuric acid, properly diluted, and the zinc cylinder is then introduced, the stopper being closed to which it is affixed, and the cover of the upper vessel removed. The gas which is generated drives the diluted acid into the upper vessel, and the further production of it ceases when the zinc is completely uncovered. We have then the bottle filled with gas; and can at any time expel it by opening the cock, and allow-



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* Zinc may be purchased at the brass-founders' or copper-smiths', under the name of speltre.

the atmosphere to press on the surface of the liquid in the glo- ar vessel.

Hydrogen gas thus obtained is not to be considered as absolutely re. An observation originally made by Dr. Priestley, and after- ards by Mr. Cuthbertson, rendered it probable that, when disen- ged by zinc, it contains a portion of that metal; and, when gene- ted by means of iron, it is apt to contain a little carbureted hy- rogen. Mr. Donovan has also shown, that, when procured from inc and dilute sulphuric acid, it is contaminated with sulphureted hydrogen and carbonic acid; and he recommends that, to obtain pure hydrogen, we should first agitate common hydrogen with lime-water during a few minutes, next with a little nitrous acid, afterwards with solution of green sulphate of iron, and finally with water. (Phil. Mag. xlviii. 138.) It appears to me, however, that carbonic acid and sulphureted hydrogen may be equally well removed by the simple process of washing the crude gas either with lime-water or with a solution of caustic potassa; and Berzelius and Dulong, in their experiments on the specific gravities of aëriform fluids, seem to have trusted entirely to the latter agent. Berzelius, however, has since shown that the gas generated from iron filings and dilute sulphuric acid, loses its odour by being passed through pure alcohol, and when the alcohol is diluted with water, and is kept a few days, an odorous volatile oil is separated, which caused the smell of the gas.

Perfectly inodorous hydrogen was also obtained by Berzelius by putting an amalgam of potassium and mercury into pure distilled water; but an acid, or muriate of ammonia, added to the water, while it accelerates the formation of gas, gives it also the same odour as that remarked in the solution of zinc by diluted sulphuric acid. This odour must, therefore, arise from impurities. (Quarterly Journal, xvii. 380; Annals of Philosophy, N.S. viii. 329.)

It must be obvious that, if the metal used for disengaging hydrogen be contaminated with sulphur, phosphorus, selenium, tellurium, or arsenic, a portion of any of those volatile substances will be dissolved by this gas, and will impart to it an odour and other properties, which are not essential to pure hydrogen gas.

II. Pure hydrogen gas has the following properties:

1. *It remains permanent over water*, or is not absorbed in a proportion exceeding $\frac{1}{30}$th the bulk of the water.

2. *As commonly procured, it has a disagreeable smell;* but pure hydrogen gas, as has been already stated, is perfectly free from al odour.

3. *It is inflammable.* This may be shown by the following exp riments:

(*a*) Fill a small jar with the gas, and, holding it with the mou downwards, bring the gas into contact with the flame of a c dle. The air will take fire, and will burn silently with a lamb flame.

(*b*) Fill with this gas a bladder, which is furnished with a s cock and with a small brass pipe. Press the air through the p and, on presenting a lighted candle to the jet, the stream will fire, and continue to burn with a pale and feeble flame, not well adapted to the purpose of artificial light. On this principle are founded the artificial fireworks without smell or smoke. They consist of pipes, having variously-sized apertures, some of which have a rotatory motion; and, to give greater brilliancy or variety of colour to the flame, the hydrogen gas is impregnated either with sulphuric ether, or some other volatile liquid, that admits of being readily diffused through it.

(*c*) In a strong bottle, capable of holding about four ounces of water, mix two parts of common air and one of hydrogen gas. On applying a lighted candle, or a red-hot wire, the mixture will burn, not silently, as in experiment (*a*), but with a sudden and loud explosion. If a larger bottle be used, it should be wrapped round with a handkerchief, to prevent the glass from doing any injury, in case the bottle should be burst.*

Mr. Cavendish made a number of experiments on the effects of firing different proportions of hydrogen gas and common air. (Phil. Trans. vol. lvi.) Nine parts of air with one of hydrogen did not fire easily, and gave a feeble sound; and four parts of hydrogen with one of air caught fire without noise, and continued to burn, but only in the neck of the bottle. Four parts of hydrogen and six of air gave the loudest sound. He found, indeed, that it was necessary that the mixture should contain more air than inflammable gas; otherwise the whole of the latter is not consumed. From theory, five volumes of common air should be sufficient for two of hydrogen, for these two volumes are adequate to saturate one volume of oxygen, which is contained in five of atmospheric air; but it is probable that a small excess of common air will render the combustion more perfect.

(*d*) The same experiment may be repeated with oxygen gas, instead of atmospherical air; changing the proportions, and mixing only one part of oxygen gas with two of hydrogen. The report will be considerably louder. The bottle should be a very strong one, capable of holding not more than 2 oz. measures, and should be wrapped round with several folds of cloth to prevent an accident.

In this case, also, the combustion is imperfect, if much more or much less oxygen be employed than is required to saturate the hydrogen. When the oxygen is 9½ times the volume of the hydrogen, or when, on the other hand, it is reduced to one-tenth of the bulk of the latter gas, the combustion in both cases is incomplete, and a portion of the hydrogen remains unconsumed. Sir H. Davy found that one measure of hydrogen and oxygen gases, mixed in due proportion for perfect combustion, was rendered uninflammable by eight additional measures of hydrogen, or nine of oxygen.

(*e*) The combustion of hydrogen and oxygen gases may be made over water, by means of the electric spark. Procure a strong tube, about three quarters of an inch diameter, and twelve inches long, closed at one end (plate ii. fig. 29, *b*). About a quarter or half an inch from the sealed end, let two small holes be drilled opposite to each other, and into each of these let a brass conductor be cemented, so that the two points may be distant from each other within the tube about one-eighth of an inch. An apparatus serving the same purpose, and much more easily constructed, may be formed by hermetically sealing a piece of brass wire, or, still better, platinum wire, into the end of a glass tube (fig. 29, *a*). With this conductor an interrupted circuit may be formed, by introducing into the tube a longer wire, one end of which terminates one-tenth of an inch from the upper one, while the other extends beyond the aperture of the tube. (See fig. 84.) Into this tube, standing over water, admit about half a cubic inch of a mixture of hydrogen and oxygen gases, in the proportion of two measures of the former to one of the latter. Hold the tube firmly, and pass an electric spark through the mixed gases. For relieving the shock, which is sometimes considerable on firing, an ingenious contrivance of Sir H. Davy, described in the Philosophical Magazine, xxxi. 3, may be employed; or the one proposed by Dr. Ure, in the 12th vol. of Annals of Philosophy, p. 381. The first effect of the combustion is a sudden and considerable enlargement of volume, which, from some experiments of Sir H. Davy, (on Flame, p. 90) probably amounts to 15 times the original bulk of the mixture. After this the gases, if pure, and in the proper proportion, will be found to have disappeared entirely.

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* These experiments may also be made advantageously by means of an apparatus sold under the name of the inflammable air-pistol.

It has been asserted by Grotthus, that a mixture of two measures of hydrogen gas with one of oxygen, cannot be inflamed by the electric spark, when expanded to 16 times its volume by diminished pressure; nor, when dilated by heat to only six times its volume. In the latter case, even a lighted taper, he asserts, does not kindle the mixture; but water is formed silently by a continued succession of electric sparks. (82 Ann. de Chimie, 37.)

Oxygen and hydrogen gases, in the proportions to form water, it is admitted by Sir H. Davy, will not explode by the electric spark when mechanically rarefied 18 times; but when the tube containing the expanded gases was artificially heated so as nearly to soften, and the electric spark then passed, a feeble flash of light was visible, which is not consistent with the last mentioned experiments of Grotthus. Sir H. Davy found, also, that dilatation by heat, instead of diminishing the explosiveness of a mixture of hydrogen and oxygen gases, in the proportions that saturate each other, on the contrary enabled them to explode at lower temperatures. Thus, a mixture of two volumes of hydrogen and one of oxygen, being expanded by a spirit lamp to 2½ volumes, instantly exploded when the upper part of the tube containing it was made red hot by another spirit lamp. He even found that a heat much below redness, (somewhere between the boiling point of mercury, and the greatest heat that can be given short of rendering glass luminous in the dark) occasions a mixture of hydrogen and oxygen gases to unite without violence or evolution of light; but that if, to a mixture so circumstanced, a red heat be suddenly applied, an explosion always takes place. (On Flame, p. 68.)

A glowing coal, if red in day light, and free from ashes, uniformly explodes a mixture of hydrogen and oxygen gases; but if its redness is barely visible in the shade, it will not explode them, but will cause their slow combination. This is not owing to rarefaction; for if an iron wire heated to whiteness be placed upon the coal within the vessel, the mixture instantly detonates.

It is rarely that oxygen and hydrogen gases can be used in such a state of purity as to leave absolutely no residuum. To determine, indeed, the purity either of the oxygen or hydrogen gas employed, it is sometimes necessary so to adjust their proportions, that the whole mixture may not be condensed by firing. If, for example, we wish *to know the purity of a quantity of oxygen gas*, we are to use about three times its bulk of hydrogen. Let us suppose that 100 measures of oxygen are detonated with 300 of pure hydrogen gas, and that the total 400 is reduced by firing to 130; the diminution of volume will be 270. This number divided by three, gives 90 for the quantity of oxygen; that is, the oxygen gas employed must have contained 10 *per cent.* of nitrogen, or of some foreign gas not condensable by hydrogen.

In the reverse process, *i. e. in determining the purity of hydrogen gas*, we mix it with more oxygen gas than is required for saturation. Suppose that to 100 of hydrogen gas we add 100 of oxygen, and that 80 measures remain after detonation. The diminution will have been 120 measures; and of these two 3ds or 80 measures are hydrogen. Hence the inflammable gas under examination must contain 20 *per cent.* of some other gas, which is most probably nitrogen. In this way we determine the proportions of hydrogen and nitrogen in any mixture composed of those two gases only.

(*f*) *Action of platinum in inflaming hydrogen gas.* It had been found by Professor Döbereiner of Jena, that the suboxide of platinum prepared according to Mr. E. Davy's method (see the Section on that metal in vol. ii.) absorbs hydrogen gas, with the extrication of sufficient heat to render the suboxide red hot, and to inflame the hydrogen, when previously mixed with atmospheric air or oxygen gas. In this process the suboxide is reduced to a metallic state. The same property, he discovered also, belongs to the light spongy platinum, obtained whenever we expose to a red heat the ammonia-muriate of that metal. If a stream of hydrogen gas be directed upon a small piece of this sponge, the latter immediately glows and kindles the gas;* or, if introduced into a mixture of oxygen and hydrogen, or common air and hydrogen, a similar ignition of the metal takes place, and is instantly followed by the detonation of the mixed gases. But if the proportion of hydrogen be such as not to be capable of detonation, the volume of the mixed gases is silently diminished, and in a few minutes, if there has been oxygen enough, all the hydrogen is absorbed; or, if there be an excess of hydrogen, all the oxygen disappears. This happens even when the oxygen, in any mixture with nitrogen, does not exceed 1 per cent. of the whole. Platinum in this form becomes, therefore, a most useful agent in eudiometry; and it is rendered still more conveniently applicable to this purpose, by mixing it with about an equal weight of alumine or china clay, adding water sufficient to form a tenacious mass, and moulding this into small balls about the size of peas, which must be dried at first slowly, and then at a stronger heat. If one of these balls, fastened to a piece of platinum wire for the convenience of withdrawing it when done with, and previously ignited by the blow-pipe, be introduced into a mixture of 100 measures of common air and 50 of hydrogen in a graduated tube over mercury, it will cause a quick diminution of volume, and in a few minutes about 87 measures only will remain. Here the diminution (63÷3 = 21) shows an absorption of 21 parts of oxygen; but in general, especially if the ball has been plunged into the mercury while hot, I have found the diminution to exceed 63 parts, owing to the action of the ball on the residuary nitrogen. This, however, may be prevented by allowing the ball to cool for a few minutes, before passing it through the mercury. The power of these balls is not in the least impaired by use, and they may be rendered as efficient as before, by exposure for a short time to the flame of the blow-pipe. At common temperatures, neither the spongy platinum, nor the balls prepared with it, acts upon any one of the gaseous compounds of hydrogen, a property which, it will afterwards be shown, may be applied very usefully in gaseous analysis. A few other metals, especially palladium, act upon mixtures of oxygen and hydrogen gases, but less efficiently. (Ann. de Chim. et Phys. xxiii. and xxiv.)

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* This property has been applied to the construction of a very useful lamp for procuring an instantaneous light.

Döbereiner has since ascertained that *moist* as well as *dry* platinum has a similar power, the only difference being that the former requires a longer time to produce its effect. This is of some importance, as it enables us to operate over water as well as over mercury. Tubes closed at one extremity, and of the requisite diameter, may be prepared for this purpose as follows. Ignite a quantity of the ammonia-muriate of platinum in the closed end; or decompose it in a solution of platinum by means of a rod of zinc. In either case, a thin film of platinum is deposited upon the interior of the tube, and adheres to it firmly. If into a tube thus prepared a mixture of hydrogen and oxygen, or of hydrogen and atmospheric air, with excess of the latter, be introduced over water, the whole of the hydrogen will be condensed in a few hours; or if the hydrogen prevail, all the oxygen will disappear. The latter fact suggests an easy method of purifying hydrogen from minute traces of oxygen; all that is necessary being to enclose it in a stopped phial, the interior surface of which has been coated in the manner described. (Ann. of Phil. N. S. ix. 313.)

The theory of this effect of platinum is very obscure. Döbereiner considers the phenomenon as an electric one, the hydrogen and platinum forming, he supposes, a Voltaic combination, in which the former represents the zinc. From the experiments of Dulong and Thenard, it appears that the mixture of atmospheric air or of oxygen with the hydrogen gas is necessary to render the platinum incandescent. That metal exerts no action, not even a slow one, on the mixed gases, when in fine powder, nor when laminated or drawn into fine wire; but when beat into the thinnest leaves which it is capable of forming, and especially when rumpled like the wadding of a gun, it was found, by the same chemists, to be efficient at common temperatures. Thicker leaves and wire acted, though slowly, at temperatures between 2 and 300° centigrade. Gold and silver in very fine leaves were efficient at a heat below that of boiling water; and spongy palladium and iridium inflamed hydrogen at common temperatures. Spongy platinum loses its power after being intensely heated. (Ann. de Ch. et de Ph. xxiii. 440.)

(*g*) *The diminution of hydrogen and oxygen gases, by the union of their bases, may be shown also by means of an apparatus exhibiting their slow combustion.* Fill a tall jar with oxygen gas, and fill also, with hydrogen gas, a bladder furnished with a stop-cock, and with a long brass pipe bent like the letter S, and drawn out to a fine point (plate iv. fig. 41.) On pressing the bladder, a stream of gas will issue from the pipe, which may be set on fire, and brought cautiously under the tall inverted jar of oxygen gas. By this contrivance, the stream of hydrogen gas will be burnt in a confined portion of oxygen gas; and, on continuing the combustion a sufficient length of time, the water will be seen to rise gradually within the jar. On the first impression of the heat, indeed, a quantity of gas will escape from the jar, which will render it difficult to ascertain what degree of absorption has actually taken place. But this loss may be prevented, by using a jar with a neck at the top, to which a compressed bladder is firmly tied. The expanded air, instead of escaping through the water, will now fill the bladder at the top; and, when the experiment has closed, and the vessels have cooled, it may be ascertained, by pressing out the gas from the bladder, what quantity of oxygen gas has been consumed. The same experiment may be much more accurately and elegantly made with the assistance of an apparatus which I have described in the Philosophical Transactions for 1808. The description cannot be understood without the plate, which is there given, and which has been copied into the Philosophical Magazine, xxii. and Nicholson's Journal, xxi.

(*h*) When a stream of hydrogen gas is burned under a tube 18 or 24 inches long, a musical sound is produced. The experiment may be made in the following manner:

Into a glass bottle are put iron filings and sulphuric acid, diluted with five or six parts of water; and a cork is fitted into the neck, through which a glass tube is passed, having its upper extremity drawn out to a capillary bore. By setting fire to the hydrogen gas,* which escapes from this extremity, a continued current or jet of flame is produced, which is allowed to pass into a tube either of glass, earthen-ware, or metal. If the tube be not too large, the flame becomes smaller as it is depressed; and when the tube covers the flame to a considerable depth, very clear sounds are produced. But, on the contrary, if the tube be too narrow, the flame will be extinguished; and, in proportion as the tube is enlarged, the sound diminishes, so that there is a certain limit at which it totally ceases. The same happens when the tube is too long. The sounds may be raised at pleasure, by either using tubes of various figures or dimensions, or made of different substances. (See Nicholson's Journ. 8vo. i. 129, and iv. 23.)

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* The gas must not be inflamed till it has been produced for some time, and has expelled all the common air of the bottle; otherwise an explosion will happen, and the bottle will be burst, with some danger to the operator.

(i) It has been discovered by M. Biot that a mixture of hydrogen and oxygen gases may be made to explode by mechanical compression. A mixture of these two gases was introduced into a strong metallic syringe, furnished with a glass bottom, and a sudden stroke given to the piston. An extremely brilliant light appeared, accompanied with a loud detonation; and the glass bottom was forcibly driven out. The repetition of this experiment, it is obvious, must be attended with some difficulty and danger. (See Nicholson's Journal, 8vo. xii. 212.) The heat given out by the sudden compression of the gases is probably the cause of the combustion which is excited. That it is not owing to compression merely, is proved by an experiment of Biot, who caused a vessel containing a mixture of the two gases to be sunk under water to the depth of 150 fathoms (equal to thirty atmospheres) without causing their combination.

The combustion of hydrogen and oxygen gases was many years ago successfully applied by Dr. Hare of Philadelphia to the purpose of exciting an intense heat by the blow-pipe. The peculiar construction of his apparatus cannot be understood without a plate, which may be seen in the *Annales de Chimie*, tom. xlv. or in the 14th volume of the Philosophical Magazine. It may be sufficient here to state, that the gases are contained each in a separate gasholder; that they are expelled by the pressure of a column of water obtained by lengthening the pipe *b*, fig. 36; and that their mixture does not take place till they nearly reach the aperture of the pipe, at the extremity of which they are inflamed. This last precaution is of considerable importance, because a violent and dangerous explosion would otherwise happen. To guard the more effectually against this accident, it is advisable to affix a valve, opening outwards, in the pipe proceeding from each gasholder, just before the junction of the two.

The power of hydrogen and oxygen gases to produce an intense degree of heat, has been much increased in consequence of a suggestion of Mr. Newman to Professor Clarke of Cambridge, that the gases should be previously mixed, then condensed into a metallic reservoir, and made to pass through a capillary tube before being set on fire.* (See plate x. figs. 4, 5, 6, and the Description of the Plates at the end of this volume.) The temperature thus produced was found adequate to the instantaneous fusion of the most refractory substances. Platinum, for instance, was not only immediately melted, but set on fire and consumed like iron wire in oxygen gas, with vivid scintillation. Considerable danger, however, arises to the operator, from the liability of the condensed gases to explode and burst the apparatus. Several expedients have been tried for the purpose of obviating this risk, the most effectual of which, suggested by Professor Cumming, consists in interposing, between the flame and the main reservoir of gases, a cylinder containing a little water or oil, through which, by means of a valve at the bottom, the gas is allowed to pass.* All, therefore, that can happen, is the explosion of the mixed gases between the inflamed jet and the surface of the oil or water, where the quantity is not sufficient to occasion any serious mischief. The more effectually to guard against danger, Dr. Clarke has since, on the suggestion of Dr. Wollaston, interposed a faggot of capillary tubes of the smallest possible diameter, between the stop-cock and the orifice of the pipe at which the gases are inflamed.† Additional safety may, also, be given to the apparatus by interposing, between the operator and the reservoir, a strong screen, through which the piston rod of the syringe may be worked horizontally, and the flame may thus be kept up for a length of time proportionate to the size of the reservoir, from which the mixed gases are drawn. This modification of the instrument renders it applicable to some of the arts, in which not only an intense but a long continued heat is required.

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* Quarterly Journal, ii. 104.

It has been discovered by Mr. Skidmore of New York, that the flame produced by Hare's blow-pipe (and that of Dr. Clarke's would doubtless exhibit the same phenomenon) continues to burn when submersed in, and in actual contact with, water, with the same splendour as in the atmosphere; the only difference being that, under water, its figure is conglobated, whereas in air it assumes that of a long slender conical pencil. Care, it appears, is required to introduce the flame slowly and deliberately into the water, in order that the flame may be prevented from receding into the interior of the tube. A piece of cork or pine wood, it was found, when brought within the action of the submersed gaseous flame, gave out a brilliant light. Metallic wires were also ignited; but this was the utmost effect producible upon them, owing, no doubt, to the conducting power of the water. (Silliman's Journ. v. 347.)

4. *Hydrogen gas, though inflammable itself, extinguishes burning bodies.*—Bring an inverted jar, filled with this gas, over the flame of a candle raised a little above the water of a pneumatic trough; and suddenly depress the jar, so that the lighted wick may be wholly surrounded by the gas. The candle will be immediately extinguished.

5. *It is fatal to animals.*—This may be shown by confining, in the

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* Quarterly Journal, ii. 379, where a plate of the improved apparatus is given.

† Thomson's Annals, ix. 327. Other improvements are suggested in the Quarterly Journal, iii. 376; Edin. Journal, ii. 187; and Ann. of Philosophy, x. 373, and N. S. i. 428. The fullest information respecting the construction and use of this instrument may be found in Dr. Clarke's book on the Gas Blow-pipe, 8vo. London, 1819.

gas, a mouse or other small animal. It may, indeed, be breathed for some time, without inconvenience, when the lungs at the outset are filled with common air; but if a forcible expiration be made, before drawing in the hydrogen gas, only two or three inspirations of the latter can be made, and even these produce great feebleness and oppression about the chest. It has been found, also, to change the tone of the voice. This effect on the person speaking, is observed immediately after ceasing to breathe it; but it soon goes off. (Quart. Journal, ix. 182, and xx. 293.)

6. *It is considerably lighter than atmospherical air, and indeed is the lightest of all elastic fluids.*—The earlier attempts to ascertain its specific gravity appear to have given too large numbers, probably on account of the impurity of the gas submitted to experiment. Kirwan made 100 cubic inches (thermometer 60°, barometer 30) to weigh 2.613 grains; Lavoisier 2.372; and Fourcroy, Vauquelin, and Seguin, 2.75. Even MM. Biot and Arago found the same quantity to weigh 2.23, which would make the specific gravity of the gas 0.07321. Dr. Thomson, (First Princ. of Chem. i. 71), reduces it to 0.06940, which is precisely the number deduced by Dr. Prout from the composition and specific gravity of ammonia. Hence 100 cubic inches, at a mean pressure and temperature, weigh 2.119 grains.

(*a*) Let a jar filled with this gas stand, for a few seconds, with its open mouth upwards. On letting down a candle, the gas will be found to have escaped, and to be replaced by common air.

(*b*) Place another jar of the gas inverted, or with its mouth downwards. The gas will now be found to remain a short time in the jar, being prevented from escaping upwards by the bottom and sides of the vessel.

(*c*) Fill with hydrogen gas, a bladder furnished with a stop-cock; and adapt to this a common tobacco pipe. Dip the bowl of the pipe into a lather of soap, and, turning the cock, blow up the lather into bubbles. These bubbles, instead of falling to the ground, like those commonly blown by the mouth, will rise rapidly into the air. On this property of hydrogen gas is founded its application to the raising of balloons.

(*d*) The experiment may be varied by filling the bladder with a mixture of two parts of hydrogen gas, and one of oxygen gas. Bubbles, blown with this mixture, take fire on the approach of a lighted candle, and detonate with a loud report. It is proper, however, not to set them on fire, till they are completely detached from the bowl of the pipe; otherwise the contents of the bladder will be exploded, with considerable danger to the operator.

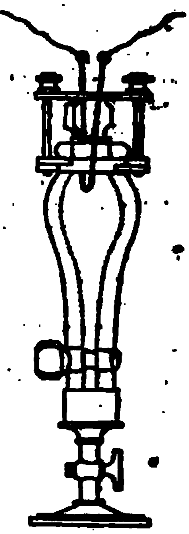
In this place a property of hydrogen gas may be described, which it possesses in common with all other aëriform bodies, *viz.* a tendency to diffusion through any other elastic fluid, with which it may be brought into contact. Common or inelastic fluids are capable of remaining in contact with each other for a long time without admixture. Thus if we half fill a wine glass with spirit of wine tinged with any colouring ingredient, and then, by means of the dropping tube, fig. 15, introduce under it a quantity of water, the spirit floats on the water, and the two surfaces remain perfectly distinct, provided we carefully avoid agitation or unequal changes of temperature. But this is not the case with elastic fluids or gases, which, it has been discovered by Mr. Dalton, penetrate each other, and become thoroughly mixed under all circumstances. (Manchester Memoirs, vol. i. new series.) The fact, with respect to hydrogen and oxygen gases, may be proved by a very simple apparatus.

Provide two glass vials, each of the capacity of about an ounce measure, and also a tube open at both ends, 10 inches long and one 20th inch bore. At each end, the tube is to be passed through a perforated cork, adapted to the necks of the vials. Fill one of the bottles with hydrogen gas, and the other with oxygen gas; place the latter on a table with its mouth upwards, and into this insert the tube secured by its cork. Then, holding the hydrogen bottle with its mouth downwards, fit it upon the cork at the top of the tube. The two bottles, thus connected, are to be suffered to remain in this perpendicular position. After standing two or three hours, separate the vials, and apply a lighted taper to their mouths, when it will almost certainly occasion an explosion in both. The hydrogen gas, though sixteen times lighter than the oxygen, must, therefore, have descended through the tube from the upper into the lower vial; and the oxygen gas, contrary to what might have been expected from its greater weight, must have ascended through the tube, and displaced the lighter hydrogen.

Experiments of this kind, it has been shown by Mr. Dalton, may be extended to all the other gases, as has been done by himself, and subsequently by Berthollet (Mem. de la Soc. d'Arcueil, tom. 2d); but to prove the interchange of place with respect to other gases, tests of a different kind are necessary, which require a previous knowledge of the properties of those gases. They establish the conclusion, *that elastic fluids, which have a sufficiently free communication with each other, tend to mutual diffusion, and that this tendency is even sufficient to overcome the obstacle of specific gravity, the heavier rising into the lighter, and the reverse.* It is obvious, therefore, that different elastic fluids, when once thoroughly mixed, cannot separate, and arrange themselves according to their respective specific gravities.

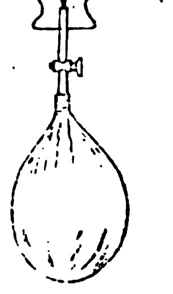
ART. I.—*Hydrogen with Oxygen.—Synthesis, or Composition, of Water.*

It has already been stated, that oxygen and hydrogen gases, when fired over water in the proper proportions, wholly disappear. To ascertain the nature of the product thus formed, the experiment must be repeated over mercury in a similar manner, by means of the detonating tube (pl. ii. fig. 28,) or (which is still better) in a very strong glass vessel, (see the annexed figure) capable of holding about half a pint, and furnished, (besides the proper contrivance at the top, for taking an electric spark in it,) with a brass cap and cock, by means of which it can be screwed to the transfer plate of



an air pump. When exhausted, it may be filled with a mixture of oxygen and hydrogen gases, in the proportion of one measure of the former to two of the latter, and an electric spark may be passed through the mixture. After the explosion, when time has been given to the vessel to cool, a sensible quantity of moisture will have condensed on the inner surface of the vessel, and by repeating the operation frequently, a sufficient quantity of fluid may be collected to show that water is the only product. The water, produced in this mode, is not, however, to be considered as a compound of the two gases, but only of their bases; for the light and caloric, which constituted the gases, escape, in considerable part, during the combustion. Every gas, it must be remembered, has at least two ingredients; the one, gravitating matter, which, if separate, would probably exist in a solid or liquid form; the other, an extremely subtile fluid, termed caloric. In the example before us, caloric (and perhaps electricity and light) is a common ingredient both of hydrogen and oxygen gases; but the two gases differ in having different bases. The basis of the one is called hydrogen, of the other oxygen; and water may, therefore, be affirmed to be a compound, not of hydrogen and oxygen *gases*, but of hydrogen and oxygen. Its composition may be proved in two modes; by synthesis, *i. e.* by joining together its two elementary ingredients; and by analysis, in other words, by separating its constituent parts, and again exhibiting them in a distinct form.

I. Fill, with hydrogen gas, a bladder, furnished with a stop-cock and bent pipe (fig. 41, *e*). Then pour into a shallow earthen dish as much quicksilver as will about half fill it, and invert over this a glass bell, perfectly dry, and full of common air. Expel the hydrogen gas through the pipe; light the stream, and bring it under the glass bell, by raising this, and depressing it into the mercury, as soon as the inflamed gas is introduced. A portion of air will escape, at first, in consequence of the rarefaction. As the combustion continues, water will form, and will condense on the sides of the glass. This water is produced by the union of hydrogen with the oxygen contained in the atmospheric air.



II. Those persons who are not possessed of a sufficient quantity of quicksilver to make the above experiment, may substitute the following: procure a large glass globe, capable of holding three or four quarts, and having two openings, one of which may resemble the pipe of a quilled receiver. In order to increase the condensing surface, the latter may be covered by a cylinder of thin glass closed at one end. Inflame a stream of hydrogen gas, proceeding from a bladder (see the figure) and introduce it into the cavity of the globe. The rarefied and vitiated air will ascend through the aperture of the globe, and a constant supply of fresh air will be furnished from beneath. By this combustion, a quantity of water will be generated, which will be condensed on the inner surface of the vessel.

III. A simple and ingenious apparatus, less costly than any other adapted to the purpose of exhibiting the composition of water, was invented by the late Mr. Cuthbertson. It is described and figured in Nicholson's Journal, 4to. ii. 235; or in the Philosophical Magazine, ii. 317;* and also in plate iv. of this work, figs. 33 and 34.

In using this apparatus, however, instead of two glass receivers for the oxygen and hydrogen gases, standing inverted in a trough of water, I employ a couple of gazometers; and with this alteration, the experiment is more easily managed, as well as more striking. The apparatus, thus modified, consists of a large glass receiver or bottle *a* (pl. iv. fig. 34), with an opening at the bottom, into which is cemented a piece of brass, perforated with two holes. This brass piece is represented of a larger size in fig. 33; the aperture *a* conveying the oxygen gas, and *b* the hydrogen. Before commencing the experiment, the cock *e*, fig. 34, is screwed, by means of a collar-joint,† to the cock *b* of the gazometer, fig. 35, containing oxygen gas; and to the cock *d*, by the same means, is affixed another gazometer, filled with hydrogen gas.

When it is intended to ascertain, accurately, the proportion of gases consumed and of water generated, the receiver *a*, previously weighed, is first exhausted by an air-pump, with which it may be connected by the female screw at *c*. The quantity of common air left in the receiver may be determined, by enclosing a gauge within it: or after exhausting the receiver, oxygen gas may be admitted; its contents pumped out a second time; and again renewed by fresh oxygen from the gazometer, the quantity of which may be measured by the graduated scale. The receiver being thus filled with oxygen gas, and accurately closed by a cock at *c*, a succession of sparks is to be passed, from the prime conductor of an electrical machine, between the platinum knob of the bent wire within the receiver, and the point of the brass cone. While the sparks are transmitted, the cock *d* is to be opened. A stream of hydrogen gas will immediately issue from the aperture at the point of the cone, and will be inflamed by the electric spark, as represented fig. 33. The cock *e* is now to be opened, and the size of the flame of hydrogen gas regulated by partly shutting the cock *d*. As the volume of hydrogen gas consumed is double that of the oxygen; and the pipe, which transmits it [illegible] less diameter than that conveying the latter, about twice the pressure is required to expel the hydrogen. This is given, by lessening, in that proportion, the weight of the counterpoises (*e e*, fig. 35) of the gazometer containing hydrogen.

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* In the same volume of the Philosophical Magazine, an interesting account may be consulted of the principal experiments on the composition of water, accompanied by neat and perspicuous engravings of the apparatus employed in them.

† See pl. v. fig. 47; and the corresponding description of the structure of this joint, in the explanation of the plates at the end of the work.

During the combustion, the moveable vessel *c*, fig. 35, of each gazometer, descends; and, by observing the graduated scales, it will be seen that two measures of hydrogen gas are consumed for each measure of oxygen. It is necessary to keep the receiver cool by means of wet cloths; and, when this is done, the water which is produced will condense into drops on the inside of the receiver, and collect at the bottom. At the conclusion of the experiment, the receiver is to be again weighed, and the increase noted. The quantity of gases consumed is to be observed, and their actual weight computed, by means of the table given in the Appendix. It will be found that the weight of water produced is very nearly equal to that of the two gases expended; that is to say, for every hundred grains of water generated in the receiver, 88.3 grains of oxygen gas, and 11.7 grains of hydrogen gas (equal by measure to about 250 cubic inches of the former, and 500 of the latter,) will have disappeared from the gazometers.

Of the Proportion of the Elements of Water.

The precise determination of the proportions of oxygen and hydrogen in water is a problem of great importance, not only on account of the fact itself, but of its influence on the general theory of chemistry. The results of almost all the earliest experiments tended to prove that water is a compound of 85 parts by weight of oxygen, and 15 of hydrogen. These numbers were afterwards corrected by Fourcroy and his associates to 85.7 of oxygen, and 14.3 of hydrogen; and in 1805 it was shown by Humboldt and Gay Lussac, that the quantity of aqueous vapour, which gases always contain, being subtracted, it is a nearer approximation to truth to state the proportions at 87.4 and 12.6. It is admitted, on all hands, that water is formed by the union of two volumes of hydrogen gas, and one volume of oxygen gas. The greatest deviation from those numbers that has ever been contended for is, that 100 measures of oxygen gas combine with 197 measures of hydrogen. A difference, however, so difficult to ascertain, on account of its minuteness, may be neglected; and it may be safely assumed, that the general statement of one volume of oxygen to two of hydrogen is correct.

In determining the proportion of the elements of water, every thing will depend, therefore, on the precision with which the specific gravities of oxygen and hydrogen gases are ascertained. Taking the results of Biot and Arago (*viz.* 1.10359 for oxygen gas, and 0.07321 for hydrogen gas,) the proportion of the elements of water should be

Oxygen - - -	88.286 - -	7.534
Hydrogen - -	11.714 - -	1.
	100.	

These proportions do not materially differ from those formerly determined by Berzelius (81 Ann. de Ch. 25), *viz.*

Oxygen	88.246	7.507
Hydrogen	11.754	1.
	100.	

The most recent experiments, however, on the specific gravities of oxygen and hydrogen gases, lead to an alteration in the statement of the composition of water, as determined by its synthesis. According to the results of Dr. Thomson, (First Princ. of Chem. i. 71,) oxygen gas is precisely 16 times specifically heavier than hydrogen gas, and, according to Berzelius and Dulong, a very little more than 16 times. That these are to be considered, however, as merely approximations to the true proportional numbers, has been well argued by Mr. Rainy. (Ann. of Phil. 2d series, xi. 187.) But, if we take a mean (*viz.* 16 to 1) as the nearest approximation, both gases being supposed perfectly dry, it will follow, since water consists of two volumes of hydrogen and one of oxygen, that eight parts by weight of oxygen and one of hydrogen constitute water, or it consists of

Oxygen	88.9	8
Hydrogen	11.1	1
	100.	9

And if water be constituted of one atom of oxygen united with one atom of hydrogen, the atom of oxygen will be represented by 8, and that of hydrogen by 1; or, representing oxygen by 10, hydrogen will be denoted by 1.250. It must be allowed, however, to be possible, though it is a much less probable view of the subject, that water may be a compound of two atoms of hydrogen with one of oxygen, which would double the weight of the atom of oxygen, and make it 16. But it may be shown to be consistent with mechanical principles, that the most energetic combination of any two elements is that in which they are united particle to particle. Until, therefore, the contrary can be established, we may assume, with Mr. Dalton, that water is a binary compound of 1 atom of oxygen, and 1 atom of hydrogen: and, adding the weights of these atoms together (8 + 1) an atom of water will weigh 9. The same proportions, expressed by different numbers, as proposed by Dr. Wollaston, will make the relative weight of an atom of water 10 + 1.250 = 11.250; the only difference, in this way of stating the fact, being, that oxygen, instead of hydrogen, is made the decimal unit.

By the combustion of hydrogen gas, either in oxygen gas or in atmospheric air, a large quantity of heat is evolved, the source of which, as well as of the light which is also extricated, is probably to be traced both to the oxygen gas and to the combustible body. Several attempts have been made to measure the caloric thus set at liberty. Lavoisier, with the aid of his calorimeter, obtained results which led him to assign 295½ lbs. of ice as the quantity melted by the combustion of a pound of hydrogen gas. Dr. Crawford, by a different process, made it 480 lbs.; and Mr. Dalton, from experiments on the rise of temperature produced in a known quantity of water by burning [illegible] volume of hydrogen, calculates the ice that would be melted by the combustion of a pound of hydrogen to be 320 lbs. The wide difference between these several numbers shows the necessity of fresh investigations of the subject. From recent experiments, Mr. Dalton calculates that the heat, evolved by the union of oxygen and hydrogen gases, would raise the temperature of the same weight of water 6500°. (New Syst. ii. 283.)

Analysis, or Decomposition of Water.

The analytical experiments on water are of two kinds: 1st, Such as present us with one of its ingredients only, in a separate and distinct form; 2dly, Such as present us with its two component principles, hydrogen and oxygen, mixed together in the state of gas.

I. Of the first kind are the following:

1. Procure a gun-barrel, the breech of which has been removed, so as to form a tube open at each end. Fill this with iron wire, coiled up in a spiral form. To one end of the barrel adapt a small glass retort, partly filled with water, and to the other a bent glass tube, the open end of which terminates under the shelf of the pneumatic cistern. Let the barrel be placed horizontally (or rather with that end, to which the retort is fixed, a little elevated) in a furnace, which has two openings in its body opposite to each other. (Pl. iv. fig. 40.) Light a fire in the furnace; and, when the gun-barrel has become red-hot, apply a lamp under the retort. The steam of the water will pass over the red-hot iron, and will be decomposed. Its oxygen will unite with the iron; and its hydrogen will be obtained in the form of a gas. This is the readiest and cheapest mode of procuring hydrogen gas, when wanted in considerable quantity.

2. The same experiment may be repeated, substituting an earthen tube for a gun-barrel, and weighing the iron wire accurately, both before and after the experiment. The iron will have gained weight very considerably; and, if attention be paid to the weight of the water that escapes decomposition, by an addition to the apparatus (fig. 40, *e*), and to the weight of the hydrogen gas obtained, it will be found that the weight gained by the iron, added to that of the hydrogen gas, will make up exactly the weight of the water that has disappeared.

3. Water may be decomposed, in a similar apparatus, over charcoal instead of iron. The products, however, are different in this case, as will appear from a subsequent section.

4. Another mode of effecting the decomposition of water yet remains to be mentioned, in which not the hydrogen, but the oxygen, is obtained in a gaseous state. This is by the action of living vegetables, either entire, or by means of their leaves only. Fill a clear glass globe with water, and put into it a number of green leaves, from almost any tree or plant. A sprig or two of mint will answer the purpose perfectly well. Invert the glass, or place it,

with its mouth downwards, in a vessel of water. Expose the whole apparatus to the direct light of the sun, which will then fall on the leaves surrounded by water. Bubbles of air will soon begin to form on the leaves, and will increase in size, till at last they rise to the top of the vessel. This process may be carried on as long as the vegetable continues healthy; and the gas, when examined, will prove to be oxygen gas, nearly pure. In this experiment, the hydrogen combines with the plant, to the nourishment and support of which it contributes, while the oxygen is set at liberty.

II. The processes by which the elementary parts of water are separated from each other, and are both obtained in an aëriform state, as a mixture of hydrogen and oxygen gases, are dependent on the agency of electricity.

1. The first of these experiments requires for its performance the aid of a powerful electrical machine. This fact was the discovery of a society of Dutch chemists; and the principal circumstance in the experiment is the transmission of electrical shocks through a confined portion of water. The apparatus employed in the experiment of Messrs. Dieman and Van Troostwyk is a glass tube, about one-eighth of an inch diameter, and twelve inches long, one of the ends of which is sealed hermetically, a gold wire being inserted at this end, and projecting about an inch and a half within the tube. About the distance of five-eighths of an inch from the extremity of this another wire is to be fixed, which may extend to the open end of the tube. The tube is next to be filled with distilled water, and to be placed inverted in a vessel of the same. When thus disposed, electrical shocks are to be passed between the two ends of the wire through the water; and, if these shocks be sufficiently strong, bubbles of air will be formed at each explosion, and will ascend till the upper part of the wire is uncovered by the water. As soon as this is effected, the next shock that is passed will set fire to the mixed gases, and the water will rise again in the tube, a very small quantity of gas remaining. Now as hydrogen and oxygen gases, in a state of admixture, are the only ones that are capable of being inflamed by the electric spark; and, as there is nothing in the tube beside water that can afford them in this experiment, we may safely infer that the evolved hydrogen and oxygen gases arise from decomposed water.

2. An improved apparatus, exhibiting the same experiment with less trouble to the operator, has been invented by Mr. Cuthbertson, and is described and figured in Dr. Pearson's paper in the Philosophical Transactions for 1797, or in Nicholson's Journal, vols. i. and ii. 4to.

3. The decomposition of water by galvanic electricity is a process singularly adapted to demonstrate the fact in a simple and elegant manner. The manner of conducting it, as well as the results, have been fully explained in treating of the general principles of electro-chemical science.

Properties of Water.

It is unnecessary to give any description of water; nor, indeed, can any be offered that will apply universally to that fluid. When spoken of in the following pages, water purified by being distilled, and condensed in tubes or in other vessels which are incapable of communicating any impregnation to it, is to be understood, unless otherwise expressed. In that state it is destitute of taste and odour, and it may be kept unchanged, for any length of time, in glass vessels, upon which it has no action. The putrefaction, which water appears occasionally to undergo, is owing to the presence of other matters foreign to its nature.

The uniformity of the composition of pure water, added to other considerations, has led to its being universally employed as a standard of comparison of specific gravities. A cubic inch at 62° Fahr., and 30 inches barometrical pressure, weighs two hundred grains, and four hundred and fifty-eight thousandth parts of a grain. (Phil. Trans. 1826, p. 8.)

The experiments of Canton had long ago shown that water is compressible into smaller bulk; and Mr. Perkins, by an ingenious instrument which he calls a *piezometer*, has determined the law of condensation by different degrees of compressing force. By a pressure equivalent to 2000 atmospheres, a column of water, eight inches long, was compressed two-thirds of an inch, or one-twelfth part of its length. (Phil. Trans. 1826, p. 541.) This, however, greatly exceeds the degree of condensation calculated from the experiments of Professor Oersted, a brief summary of which is given in the An. de Ch. et de Ph. for January 1828. The reader may also consult the memoir, published in the same work for Oct. and Nov. 1827, by MM. Colladon and Sturm.

Among the chemical properties of water, the following are some of the most important:

I. *Water contains air.*—This may be shown by placing a glass vessel of water, fresh from a spring, or even of distilled water that has been exposed a few days to the atmosphere, under the receiver of an air-pump. During the exhaustion of the receiver, bubbles of air will be seen to ascend very plentifully. Much air escapes also from water during boiling, and may be collected by a proper apparatus. The same fact may also be exhibited by filling a barometer tube, about thirty-two inches long, sealed at one end, with quicksilver, except about four inches, and the remainder with water. On inverting the open end of the tube in quicksilver, bubbles of air will in a short time rise from the water. Water deprived of air regains it by exposure to the atmosphere.

The kind of gas extricated from the water of a spring at a considerable distance from the surface, I have made the subject of experiment. (Phil. Trans. 1803.) From 100 cubic inches of the water, or about 3½ wine pints, 4.76 cubic inches of gas were separated, of which 3.38 were carbonic acid gas, and 1.38 air of the same standard as that of the atmosphere. It is probable, however, that the proportion of gaseous contents differs in the water of different springs, for Mr. Dalton states the average of his experiments to be about 2 cubic inches of gas from 100 of water, and that the air expelled, after losing 5 or 10 per cent. of carbonic acid by the action of lime-water, consisted of 38 per cent. oxygen and 62 nitrogen. (New Sys. 271.)

Every gas is absorbed by water which has been deprived of all or the greatest part of its air by long boiling. The quantity, however, which water is capable of absorbing, varies considerably with respect to the different gases. Those gases, of which only a small proportion is absorbed, require long continued agitation in contact with water. The following table has been drawn up by Mr. Dalton from the combined results of his own experiments and mine.

Water absorbs, at the mean pressure and temperature of the atmosphere,

Of carbonic acid gas	its own bulk.
sulphureted hydrogen	do.
nitrous oxide	do.
olefiant gas	1-8th.
oxygen gas	1-27th.
nitrous gas	do.
carbureted hydrogen	do.
carbonic oxide	1-64th.
azotic gas	do.
hydrogen gas	do.

The accuracy of these results has been called in question by Saussure, who, from a series of experiments of his own, has deduced the numbers expressed in the second column of the following table. (Thomson's Annals, vi. 340.)

Gases.	100 vols. of water absorb (Dalton and Henry)	100 vols. of water absorb (Saussure)
Sulphureted hydrogen	100.	253.
Carbonic acid	100.	106.
Nitrous oxide	100.	76.
Olefiant gas	12.5	15.3
Oxygen	3.7	6.5
Carbonic oxide	1.56	6.2
Azotic	1.56	4.1
Hydrogen	1.56	4.6

Absolutely pure water (not merely freed from air by boiling,) according to recent experiments of Mr. Dalton, takes up 2¼ per cent. of its bulk of azotic gas, and 2 per cent. of hydrogen. In the other gases, with the exception of carbonic oxide, which he had already, in his System, p. 375, corrected to 1-27th the bulk of the water, he is disposed to abide by his original numbers, and to consider those of Saussure as much greater than the truth. (Ann. of Phil. vii. 215.)

When water, impregnated with any gas, is frozen, the gas is expelled. This, at least, is asserted by Dr Priestley (iii. 361) of carbonic acid, nitrous and fluoric acid gas; but sulphurous acid he states to be an exception. The subject, however, requires further experiments.

II. *Water is contained in the air of the atmosphere, even during the driest weather.*—Expose to the air, in a shallow vessel, a little subcarbonate of potassa, or common salt of tartar; in a few days it will have become moist, or *deliquiated*, and will have increased considerably in weight. Water, also, exposed to the air in a shallow vessel, slowly disappears, being taken up by the atmosphere. Saussure states the quantity of water in a cubic foot of air, charged with moisture at 65° of Fahrenheit, to be 11 grains. The quantity of water that may be extracted from 100 cubical inches of air, at 57° Fahrenheit, is 0.35 of a grain; but, according to Clément and Désormes, at 54° Fahr., only 0.236 of a grain can be detached by exposure to recently fused chloride of calcium. Their experiments and those of Mr. Dalton concur in proving that, at the same temperature, equal volumes of all the different gases give up the same quantity of water to deliquescent salts. The portion of humidity which they thus abandon has been called *hygrometric water*. Several bodies absorb water from the atmosphere, which can scarcely be supposed to have an affinity for it, and again give it up on the application of a gentle heat. Such are almost all substances in the state of powder; porous paper; soils which have been artificially dried; parched oatmeal; and even the filings of metals. Some powders retain the moisture they have absorbed, till a considerable heat is applied. The nature of this combination is not exactly understood. (See Berzelius, 79 Ann. de Ch. 118.)

There are two different theories of the state in which water exists in the atmosphere and in other gases. By most writers, water has been considered as united to air by chemical affinity; and, when abstracted by other bodies, (such as sulphuric acid, lime, and the whole class of deliquescent salts,) the effect has been ascribed to the superior affinity of those bodies for water. Saussure had long ago shown that the quantity of water existing in any space, at a given temperature, is the same, whether the space be void or filled with air; and Mr. Dalton has since more distinctly proved that the vapour of water, mixed with air, or with any other gas permanent over water, differs in no respect from pure steam, and is subject to the same laws. Aqueous vapour constitutes, in his opinion, a distinct and independent atmosphere, the elastic force of which forms, at different temperatures, different proportions of the elastic force of the whole; for example, at the temperature of 65° Fahrenheit, it gives to air $\frac{1}{30}$ of its elasticity. According to this view, a volume of air or gas at any temperature, saturated with moisture, contains as much steam as would exist, at that temperature, in a vacuum of equal capacity. This view, confirmed by the experiments of Gay Lussac, is much more probable than that which explains the phenomena by chemical affinity; and it is supported especially by the fact, that the absorption of caloric is precisely the same in amount in spontaneous as in forced evaporation. It steers clear also of the inconsistency attending the supposition, that the vapour, contained in the atmosphere at ordinary temperatures, is in a different state from that existing in a Toricellian vacuum; and, again, that water below 212° Fahr. is chemically combined with the atmosphere, and above 212° assumes a new form, and becomes a distinct elastic fluid called *steam*. It is certainly much more reasonable to suppose that water, whenever it exists as an elastic fluid, whether distinct from or mixed with others, is maintained as such by one and the same cause, *viz. by its constituent caloric*, and not by chemical solution in any gas or mixture of gases.

It may be asked why the diffusion of vapour in the atmosphere is not instantaneous, as it is *in vacuo?* This appears to be owing to the *vis inertiæ* of the particles of air, and the resistance is probably similar to that which a stream of water meets with in descending through a bed of pebbles. The evaporation of water, we find, is accelerated either by raising its temperature, by increasing its surface, or by causing a current of air to pass over it. In the first case, the force of the vapour, or its power of overcoming obstacles, is increased; and the quantity of water evaporated in a given time bears, as Mr. Dalton found, a proportion to the force of vapour of the same temperature. This is shown by the following table:

Temperature.	Force of Vapour, in inches of mercury.	Grains of Water, evaporated per min.
212° Fahr.	30	30
180	15	15
164	10	10
152	7.5	7
144	6	6
138	5	5

The evaporation from a vessel containing water at 212° in a still atmosphere, Mr. Dalton found, was increased one-half by a current; and a still stronger current, he thinks it probable, would have doubled it. In this case, the removal of a mechanical obstacle conspires with the force of the vapour; and, as steam rises only from the surface of water, it is obvious that increase of surface must quicken evaporation by augmenting the quantity of vapour of a given force. Another circumstance, influencing the rate of evaporation, is the force of the vapour actually existing in the atmosphere at the time, for the less this force, or, in other words, the less the quantity of vapour in the air, the more rapid is the evaporation from a given surface of water of a given temperature. Hence an increase of temperature in the air quickens evaporation, by enabling the atmosphere to hold steam of greater force; and, by a current of heated air, we apply two causes conjointly, both of which powerfully tend to quicken evaporation.

The method of finding the force of vapour in the atmosphere, employed by Mr. Dalton, is extremely simple and elegant. A glass jar, or a common tumbler, (the thinner the glass the better,) may be filled with cold spring water, fresh from the well. If dew be immediately formed on the outside, the water is poured out and allowed to stand a while to increase in heat; the glass is then well dried with a linen cloth, and the water poured in again. This operation is continued till dew ceases to be formed, and then the temperature of the water is to be observed, and opposite to it in the Table (see the Appendix) will be found the force of vapour in the atmosphere. This must be done either in the air or at an open window; because the air within is generally more humid than that without. Spring water in this country is commonly about 50° Fahr., and will mostly answer the purpose during the three hottest months of the year: in other seasons, artificial cold, produced by dissolving a little of any fit neutral salt in the water, is required.

In the torrid zone, the aqueous atmosphere is equal to a pressure of six-tenths of an inch of mercury, and increases even to one inch. In this climate, Mr. Dalton has observed it above half an inch in summer; but in winter it is sometimes so low as one-tenth, or even half a tenth; and at the same place, and during the same season, it is constantly varying with the temperature of the air. It is easy then to see, at any time, what proportion it constitutes of the whole weight of the atmosphere of any given place, by taking the *dew point*, observing the barometer at the time when the experiment is made, and referring to Mr. Dalton's Table of the Force of Vapour.

Besides this method of determining the degree of moisture of the air by ascertaining the *dew point*, a variety of instruments have been also contrived for the same purpose. They are called *Hygrometers*, and consist, for the most part, of some substance, such as a human hair or a fine slip of whalebone, which is elongated by a moist atmosphere, and shortened by a dry one. The extreme points are attained by placing it, first in air artificially dried, and then in air rendered as humid as possible. The degree of expansion or contraction is rendered more sensible by connecting it with an axis, which moves a circular index, like the finger of a clock. Mr. Leslie, by a slight modification of his differential thermometer, makes it serve the purpose of an hygrometer; for if one of the balls be covered with silk, and then moistened with water, the rate of evaporation will be shown by the degree of cold produced, as indicated by the descent of the liquid in the opposite leg of the instrument. The drier the air, the quicker will be the evaporation, and the greater the effect in moving the liquid within the instrument.

IV. *Water enters into combination with various solid bodies, and entirely loses its fluid form.* In many instances it unites in a definite proportion; and it is held by so powerful an affinity, as not to be separated by a very high temperature. Such compounds are termed *Hydrates*. The pure alkalies, potash, and soda, retain, for example, even after fusion, about one-fifth their weight of water, which can only be separated by some body having a stronger affinity for the alkali. In all hydrates, at least one atom of water must be present, or it must be contained in them in such quantity, as to bear the proportion of nine at least to the weight of the atom or atoms with which it is united. If, for example, the weight of the atom of potassa be 48, we cannot have a true *binary* compound of water and potassa, in which the former bears to the latter a less proportion than that of 9 to 48. And if, in any instance, water is obtained from a compound in a proportion less than that of the weight of the atom of water to the weight of the atom or atoms of the body with which it is associated, we may take for granted that it is held mechanically and accidentally, and not as a true chemical constituent. Such appears to be the nature of the union of water with certain neutral salts (common salt and sulphate of potassa, for example,) which contain only 1 or 2 per cent. of their weight of water.

V. *Water dissolves a great variety of solid bodies.*—The substances on which it exerts this effect are said to be soluble in water; and there are various degrees of solubility. See chap. i. and the Table in the Appendix.

VI. *During the solution of bodies in water, a change of temperature ensues.*—In most instances, an absorption of caloric (in other words, a production of cold) is attendant on solution, as in the examples given in the chapter on caloric. But, in other cases, caloric is evolved, or heat is produced. Thus common salt of tartar, during solution in water, raises the temperature of its solvent; and caustic potassa, in a state of dryness, does the same still more remarkably. But carbonated and pure potassa, when crystallized, observe the usual law, and absorb caloric during solution. Now as their difference, in the crystallized and uncrystallized state, depends chiefly on their containing in the former, but not in the latter, water chemically combined, we may infer, that the cold, produced during the solution of salts, is occasioned by the conversion of the water, which exists in these bodies, from a solid to a liquid form. Some doubt, it must be acknowledged, is thrown on this conclusion by the observation of Gay Lussac, that a saturated solution of nitrate of ammonia, when mixed with water of the same temperature, is cooled 8 or 9 degrees. (Ann. de Ch. et de Phys. i. 215.)

VII. *During the solution of salts in water, a quantity of air is disengaged.*—This air was partly contained mechanically in the salt, and partly in the water. That it does not arise entirely from the former source, is proved by varying the experiment in the following manner. Let an ounce or two of sulphate of soda be put into a phial, and on this let as much water be poured as will completely fill the bottle. The air contained in the pores of the salt will be thus disengaged; but only a small portion of the salt will be dissolved. Let the phial be shaken, and the whole of the salt will disappear; a fresh portion of air being liberated during its solution.

VIII. *During the solution of bodies, the bulk of water changes.*—Take a glass globe, furnished with a long narrow neck (commonly termed a matrass, see fig. 4,) and put into it an ounce or two of sulphate of soda. Then, add as much water as will fill the globe, and about three-fourths of the neck. This should be done with as little agitation as possible, in order that the salt may not dissolve, till required. Mark, by tying a little thread, or by a scratch with a file, the line where the water stands; and then agitate the matrass. The salt will dissolve; air will be set at liberty; and, during the solution, the water will sink considerably below its level. The contraction of bulk is owing to the diminution of temperature; and, when the water has regained its former temperature, it will be found that its bulk is increased by the addition of the salt. The late Bishop Watson observed, that water exhibits a manifest augmentation of bulk, by dissolving only the two thousandth part of its weight of salt; a fact sufficiently decisive against that theory, which supposes pores in water capable of receiving saline bodies without an augmentation of volume.

IX. *Water appears to have its solvent power increased, by diminishing the pressure of the atmosphere.*—Into a Florence flask, put half a pound of sulphate of soda; pour on it barely a pint of water, and apply heat so as to boil the water. The whole of the salt will be dissolved. Boil the solution for several minutes pretty strongly, so as to drive out the air; and cork the bottle tightly, immediately on its removal from the fire. To prevent more completely the admission of air, tie the cork over with bladder. As the vessel cools, an imperfect vacuum will be formed over the solution; for the steam, which rises during the ebullition, expels the air, and takes its place. The steam is condensed again, when the vessel cools. The solution, when perfectly cold, may be shaken without any effect ensuing, so long as the vessel is kept closely stopped; but, on removing the cork and shaking the vessel, the solution will immediately congeal, and heat will be produced. This experiment, besides the principle which it is peculiarly intended to illustrate, exemplifies also the general rule already laid down, that caloric is always evolved, during the transition of bodies from a fluid to a solid state; and it furnishes an instance exactly the reverse of that in which cold is produced, or caloric absorbed, during the solution of salts. It is proper, however, to remark that the observations of Dr. Coxe, of Philadelphia, have thrown some doubt over the cause of these phenomena, which appears to require further investigation. From his experiments, the exclusion of air does not seem to be absolutely necessary; for saline solutions continued fluid, if perfectly at rest, though freely exposed to the atmosphere, but immediately became solid when shaken. (Thomson's Annals, vi. 101.) The effect of mechanical disturbance in promoting saline crystallization, under circumstances where it has been ascribed to the renewed contact of air with the surface of the solution, is illustrated also by some experiments of Dr. Ure. (Quart. Journ. v. 106.)

X. It is unnecessary to add any thing to what has been already said in a former section, respecting the combination of caloric with water constituting steam; or to the history of the phenomena attending its conversion into ice; except that, during the latter change, electricity as well as caloric is evolved, (Ann. de Chim. et de Phys. xxvii. 111,) and that its bulk is enlarged in the proportion of nine to eight. In consequence of this expansion, water, during congelation, is capable of bursting the strongest iron vessels.

It is remarkable, that this enlargement of the bulk of water begins, long before its temperature has descended to the freezing point, *viz.* at about 40° Fahrenheit. Let a thermometer bulb, and part of its tube, having a wide bore, be filled with water tinged with a little litmus, which may be introduced by the same means as those already directed for filling it with quicksilver. Immerse the bulb in water of the temperature of 40°; and, when the included water may be supposed to have attained the same degree of heat, remove the instrument successively into water of the temperature of 36° and 32°. At each immersion, the water will rise in the tube. Bring its temperature again to 40°, and it will descend to the same point as before. Place it in water of 50°, and it will again be expanded. Precisely similar effects, therefore, appear to result, in these experiments, from two opposite causes; for the bulk of water is alike increased by reducing or raising its temperature. The point, at which water is of its greatest density, was fixed by De Luc at 41° Fahr.; by Sir C. Blagden and Mr. Gilpin at 39°; and by Dr. Hope and Count Rumford, somewhere between 39° and 40°. It is contended, however, by Mr. Dalton, that, in the apparent expansion by a lower temperature, there is a deception, arising from the contraction of the glass, which must lessen the capacity of the bulb, and force the water up the stem. He apprehends, therefore, that the point of greatest density has been fixed too high by Count Rumford, Dr. Hope, and other philosophers, and that it is in reality 36° of Fahrenheit, or 4° above the freezing point. M. Biot infers also that the true maximum of density is at 38.16 of Fahr. (Thomson's Annals, ix. 434). But the recent experiments of Hallström, (Ann. de Ch. et de Ph. xxviii. 90,) place it at 39.39 F. and this we may, therefore, consider as its point of greatest density. In sea water, it appears from the experiments of Erman, Jun. that the common salt, which it contains, retards the point of maximum density, or rather, perhaps, prevents it from taking place till after congelation. (Ann. de Ch. &c. July, 1828.)

Deutoxide or Peroxide of Hydrogen.

Only one compound of hydrogen and oxygen, namely water, was known until, in July 1818, M. Thenard discovered, that by a process somewhat difficult and complicated, an additional dose of oxygen may be communicated to that fluid, and a compound may be obtained, which is possessed of a new and very remarkable train of properties.

To obtain this product, it is necessary to employ a substance, the nature and preparation of which will be described in the section on *barium*, *viz.* the *peroxide* of that metal. This compound, when acted upon by liquid hydro-chloric (muriatic) acid, abandons part of its oxygen, and is reduced to the state of protoxide (baryta), which unites with the muriatic acid, while the oxygen unites with the water. Sulphuric acid, added to the compound fluid, carries down the baryta, and sets muriatic acid at liberty, which is ready to act upon a fresh quantity of the peroxide of barium. This operation may be several times repeated, and at each repetition the water becomes charged with an additional quantity of oxygen. When the process has been carried far enough, sulphate of silver is added, to precipitate the free muriatic acid, which it replaces by a quantity of free sulphuric acid; but the latter is easily separated by adding a due proportion of baryta. This is a general outline of the process, to insure the perfect success of which seems to require many precautions, and especially the greatest attention to the purity of the peroxide of barium. Very minute instructions for the preparation of this oxygenated water are given by its discoverer, M. Thenard; but they would occupy too much room here, and I refer therefore for a detail of them to his Memoir on this subject. (Ann. de Chim. et de Phys. viii, ix; Ann. of Philos. xiii, xiv, xv; and Quart. Journ. vi. 150, 379. viii. 114, 154.)

The peroxide of hydrogen is liquid and colourless like water. It has scarcely any smell, but when applied to the tongue whitens it, thickens the saliva, and produces a taste like that of some strong metallic solutions. It attacks the skin with great rapidity, bleaches it, and occasions a smarting, the duration of which differs in different persons, and in the same person, according to the quantity applied. Its specific gravity is 1.452, and when poured into water it descends through it like syrup, though easily dissolved by agitation. Its tendency to the vaporous form is much less than that of water, and hence, when very dilute, it may be concentrated by exposing it under the receiver of an air-pump, along with any strong deliquescent substance. If continued long in this situation, however, it at length disappears. In its most concentrated form, it has not been congealed by any degree of artificial cold yet applied to it.

When once prepared, it is necessary to keep it surrounded by ice, for a temperature of 58° Fahr. is sufficient to decompose it, and to liberate oxygen gas in great abundance. The action of heat varies with its degree of concentration. Seven or eight grains of the sp. gr. 1.452, when suddenly heated, are sufficient to occasion a violent explosion; and, therefore, to obtain safely the whole of its excess of oxygen above that constituting water, it is necessary, before applying heat, to dilute it with about 20 parts by weight of water. By experiments of this kind, carefully made, M. Thenard ascertained that, admitting water to be composed of 11.71 hydrogen and 88.29 oxygen, this new compound contains exactly double that quantity of oxygen, or 11.71 hydrogen, and 176.58 oxygen, or

Hydrogen - - - - - - - -	1
Oxygen - - - - - - - - -	16

If water, then, be a compound of 1 atom of hydrogen and 1 of oxygen, the peroxide must consist of 1 atom of hydrogen and 2 of oxygen, and its representative number (hydrogen being unity) will be 17, or, oxygen being 10, it will be 21.250. This is a much more probable view of the subject than that it should consist of 1 atom of oxygen + 1 atom of hydrogen; and water of 1 atom of oxygen + 2 of hydrogen; for, in this case, the most compounded body, water, would be most difficult to decompose, which is contrary to all analogy.

Light does not exert any speedy operation on the peroxide of hydrogen. Of the metals, tin, iron, antimony, and tellurium, bring it back rapidly to the state of water. Some metals, as silver, platinum, gold, &c., when finely divided and added to it, liberate its oxygen without themselves undergoing any change, in a way which is not easily explained. Others (arsenic, molybdena, tungsten, potassium, sodium, &c.) liberate one part of the oxygen, and absorb the rest. Acids render it a more stable compound. For example, when to diluted peroxide of hydrogen, effervescing from the application of an increased temperature, we add phosphoric, sulphuric, muriatic, arsenic, acetic, tartaric, citric, or oxalic acid, the discharge of gas is suspended. Carbonic and boracic acids do not produce this effect, on account, probably, of their feeble powers as acids. Sulphurous and hydriodic acids, and sulphureted hydrogen, decompose the peroxide, and possess themselves of its oxygen.

The following substances, when added to the concentrated peroxide, occasion explosions of greater or less violence; oxide of silver, peroxide of lead, peroxide of manganese artificially prepared, osmium, silver, and platina, the two last in the finest state of division in which they can be obtained by chemical precipitation.

ART. 2.—*Hydrogen with Chlorine.—Hydro-Chloric or Muriatic Acid.*

Chlorine and hydrogen gases act with considerable energy upon each other, and with different phenomena, accordingly as the experiment is conducted.

1. If a phial be entirely filled with a mixture of hydrogen and chlorine gases in equal proportions, and a well ground stopper be introduced, no action takes place, provided light is carefully and completely excluded, even by standing some time; but, on applying a lighted taper, the gases immediately explode.

2. Let a jar, fig. 22, *a*, guarded from the light, be half filled with chlorine gas and half with hydrogen, and let a stout vessel capable of holding 4 or 6 cubical inches, and provided with a fit contrivance for passing an electric spark through it, (see page 224) be first exhausted by the air-pump, and then screwed upon *a*, and filled with the mixed gases. An electric spark may now be passed through the mixture, when a detonation will ensue, to avoid any injury from which the vessel should be wrapped in several folds of cloth. If the cock attached to the vessel be opened under mercury in about a quarter of an hour, very little of that fluid will enter, proving that the volume of gas after the experiment is scarcely diminished. That it is diminished at all, is owing to a small portion of common air being mingled with the other gases; and it was found, by Sir H. Davy, that the more perfectly this is excluded, the less is the amount of the contraction of volume. If the cock be now opened under water, and left there for a few minutes, the water will be found to have ascended and entirely filled the vessel. Hence a gas must have been generated by the combustion, which, though not absorbable by mercury, is condensable by water.

3. Let a stout and well stoppered phial, capable of holding three

or four ounce measures, be filled over water with equal volumes of chlorine and hydrogen gases, and a ground stopper introduced. Expose it to the ordinary day-light, guarding it from the direct rays of the sun, and in twelve or fourteen hours the colour of the chlorine will have disappeared; and, on withdrawing the stopper under water, the phial will be immediately filled with that fluid.

4. If the experiment be repeated, with this difference that the phial is exposed to the direct rays of the sun, the combination will take place rapidly, and a detonation will ensue, which will probably drive out the stopper. But if this should not happen, the stopper may be removed under water, which will ascend and completely fill the bottle, as in experiment 3.

This effect of solar light in promoting the action of chlorine and hydrogen gases on each other, was discovered by Gay Lussac, and, without any knowledge of his experiments, about the same period, by Mr. Dalton. The agency of light may be beautifully shown by filling a tube about half an inch diameter, and 12 inches long, with the mixed gases, and alternately shading it with an opaque cover, and exposing it to the sun's rays. The moment the tube is exposed even to the diffused light of day, a cloudiness will appear within it, and the water will ascend more or less rapidly, according to the intensity of the light. The effect even of a passing cloud is distinctly seen in retarding the rapidity of the combination, which is very striking in the full solar light. Blue light, it has been observed by Seebeck, is more effectual than red; but neither occasions the rapid union which is excited by the direct rays of the sun. (34 Nicholson's Jour. p. 220.) It is probable that in this case, the combination is favoured by increase of temperature, for it has been observed by Sir H. Davy that a mixture of chlorine and hydrogen inflames at a much lower temperature than one of oxygen and hydrogen gases, and produces a more considerable degree of heat in combustion. He ascertained, also, that the former mixture will bear a much greater rarefaction than the latter, without losing its explosive property. Oxygen and hydrogen gases ceased to explode when rarefied 18 times, but chlorine and hydrogen were still combustible, when mechanically expanded to 24 times their volume.

5. It had been supposed that the direct beams of the sun were necessary to explode a mixture of chlorine and hydrogen gases; but Professor Silliman, in the American Journal of Science (iii. 342), has related the accidental explosion of a mixture of the gases, in the quantity that filled a Florence oil flask, not only when no direct solar light fell upon it, but when the diffuse light of day was rendered more feeble than common by a thick snow storm. This fact furnishes a caution against mixing the two gases in considerable quantities.

6. Mr. Brande found (Phil. Trans. 1820) that the intense light. issuing from charcoal points connected with a powerful galvanic battery, was as effectual as solar light in acting on hydrogen and chlorine gases, and causing them to detonate; but he could not produce an analogous effect by any other terrestrial light. The

moon's rays, also, he found to be quite inefficient on a mixture of these two gases.

Muriatic or Hydrochloric Acid Gas.

When one volume of hydrogen gas has been made to combine, either silently or explosively, with one volume of chlorine, the product is two volumes of a new gas, differing essentially from either of its components, and especially in being instantly absorbed by water. To preserve it, therefore, in a gaseous state, it is necessary to confine it by quicksilver. At all common temperatures and pressures, it is permanent in this form; but it was generated by Mr. Faraday in close tubes from muriate of ammonia and sulphuric acid in a liquid state. Its refractive power was then found equal to that of liquid nitrous oxide, but inferior to that of water. The pressure of its vapour at 50° Faht. was equal to about 40 atmospheres.

As the elements of the new gas unite without condensation, its specific gravity must necessarily be the mean between those of its components, which, taking hydrogen at 0.0694, and chlorine at 2.500, is 1.2847, a number almost exactly agreeing with the experimental result of Dr. Thomson. Admitting then the relative weights of hydrogen and chlorine under equal volumes to be as 1 to 36, and that hydrochloric acid gas is constituted of an atom of each, the compound atom will be equivalent to 37, or to 46.25, oxygen being 10.

To obtain hydrochloric acid gas in sufficient quantity for the exhibition of its properties, the direct combination of chlorine and hydrogen gases is not an eligible process. It may be procured much more conveniently in the following manner. Let the tubulated gas bottle (plate ii. fig. 17) be about one-fourth, or one-third, filled with well-dried chloride of sodium (common salt) in lumps, not in powder. To this adapt the acid-holder, filled with concentrated sulphuric acid, and let the aperture of the bent pipe terminate under a jar filled with, and inverted in, quicksilver. Open the communication between the acid and the salt, by turning the cock; and immediately on the contact of these two bodies an immense quantity of muriatic acid gas will be disengaged. A common or tubulated gas bottle, or tubulated retort, will answer sufficiently well for procuring the gas. The first portions that come over may be allowed to escape under a chimney; because they are contaminated by the admixture of common air present in the bottle. The subsequent portions may be preserved for use; and the pure gas will exhibit the following qualities:—

(*a*) It has a very pungent smell; and is sufficiently caustic to blister the skin, when applied to it for some time.

(*b*) When brought into contact with common air, it occasions a white cloud. This is owing to its union with aqueous vapour, which is always present in the atmosphere.

(*c*) It extinguishes a lighted candle. Before the flame goes out, the upper part of it assumes a greenish hue, the cause of which has not yet been explained. A white vapour also surrounds the extinguished wick, owing to the combination of water, produced by the combustion of the candle, with the muriatic acid gas.

(*d*) It is heavier than common air. Gay Lussac states its specicific gravity at 1.278, and hence 100 cubic inches weigh, as nearly as possible, 39 grains; according to Sir H. Davy between 39 and 40; or to Mr. Brande 38.8. Biot and Arago make its specific gravity, by experiment, 1.2474, or, by calculation, 1.2505. Dr. Thomson finds it, by experiment, 1.284366. (First Princ. of Chem. i. 78.)

(*e*) When a succession of electrical discharges is passed through muriatic acid gas in contact only with glass, by means of an apparatus which I have described in the Phil. Trans. for 1812, the gas is partly resolved into its elements, and, after taking out the undecomposed muriatic acid gas by a few drops of water, we find a residuum of chlorine and hydrogen gases, in quantity never exceeding $\frac{1}{35}$ the bulk of the original gas. When the disengaged gases rise above this proportion, they re-combine and form muriatic acid again. If the experiment be made over mercury, the volume of the gases is diminished; the presence of chlorine is rendered evident by its effect on the surface of that fluid; and hydrogen gas remains, equivalent in volume to 1-14th or 1-16th the muriatic acid gas.

(*f*) When a mixture of oxygen and muriatic acid gases is either electrified, or transmitted through a red-hot porcelain tube, the oxygen unites with the hydrogen of the acid, and the chlorine of the latter is set at liberty. A similar mixture I find also is decomposed by being exposed, at a temperature of 250° Faht., to contact with the platinum sponge. Water is formed, and the disengaged chlorine acts on the mercury used to confine the gas. (Phil. Trans. 1824.)

(*g*) Potassium, by being heated in muriatic acid gas, liberates one third its volume of hydrogen. Heated zinc and tin disengage a volume of hydrogen equal to one half that of the muriatic acid gas, and chlorides of those metals are obtained. (Davy, Phil. Trans. 1810.)

(*h*) Charcoal, even when ignited to whiteness by Voltaic electricity in muriatic acid gas, causes no change, if the gas be previously deprived completely of moisture.

(*i*) Muriatic acid gas effects the liquefaction of a piece of ice, almost as rapidly as it would be melted by a red hot iron.

(*k*) This gas is very rapidly absorbed by water. A drop or two of water, admitted to a large jar full, causes the whole instantly to disappear. According to Mr. Kirwan, an ounce measure troy of water absorbs 800 cubical inches (*i. e.* 421 times its bulk) of muriatic acid gas; and the liquid obtained exceeds, by about one-third, the original volume of the water. Sir H. Davy (Elements, p. 252,) found that at 40° Fahr. water absorbs about 480 times its bulk of muriatic acid gas, and forms a solution of specific gravity 1.2109. One hundred grains of this acid, decomposed by nitrate of silver, indicated 40.8 of acid gas to have been condensed in it.

Dr. Thomson states (First Princ. of Chem. i. 85,) that at 69° F. one cubic inch of water absorbs 417.822 cubic inches of muriatic acid, and its volume becomes 1.3433 cubic inches. Hence 100 grains of this acid contain 103 cubic inches of gas. Its specific gravity is 1.1958, and it consists of 40.39 real acid + 59.61 water.

It is in this state of watery combination that muriatic acid is kept for chemical purposes, and all the processes for preparing the liquid acid have for their object the disengagement of muriatic acid gas, and its absorption by water. This may be effected in the following manner.

Process for preparing Liquid Hydrochloric or Muriatic Acid.

Into a tubulated retort, placed in a sand-bath, put eight parts of dried chloride of sodium (common salt); and, to the tubulure, lute the bent tube (fig. 26, *a*,) with fat lute. To the neck of the retort, affix a tubulated receiver, (fig. 30, *b*,) by means of the same lute; and to the aperture of this adapt a tube, twice bent at right angles, and furnished with Welter's contrivance for preventing absorption (fig. 31, *b*,) the longer leg of which terminates beneath the surface of water contained in a two-necked bottle. From the other neck, let a second right-angled pipe proceed; and this may terminate in a similar manner, in a second bottle containing water; the total quantity of which, in all the bottles, may be five or six parts. Let the junctures be all carefully luted; and, when they are sufficiently hardened, pour very gradually, through the bent tube, six and a half or seven parts by weight of strong sulphuric acid, making the additions at several distant intervals. On each affusion of the acid, a large quantity of muriatic acid gas will be liberated, and will be absorbed by the water of the first bottle, till this has become saturated. It will then pass on to the second bottle, and be there condensed. The water employed may amount to two-thirds the weight of the salt, and may be equally distributed between the two bottles. These it is better to surround with cold water, or, still preferably, with ice or snow; because the condensation of the gas evolves considerable heat, which prevents the water from attaining its full impregnation. When the whole of the sulphuric acid has been added, and the gas no longer issues, let a fire be lighted in the furnace, beneath the sand-bath, removing the bent tube *a*, and substituting a well-ground glass stopper. This will renew the production of gas; and the temperature must be preserved as long as gas continues to be evolved. At this period it is necessary to keep the luting, which connects the retort and receiver, perfectly cool; otherwise it will be apt to melt. To this juncture, indeed, I prefer the application of the clay and sand lute; but it should be suffered to become completely hard before the process is begun. Towards the close of the process, a dark-coloured liquid is condensed in the first receiver, consisting of a mixture of sulphuric and muriatic acids. When nothing more comes over, the operation may be suspended, and the liquid in the two receivers must be preserved in bottles with ground stoppers. It consists of liquid muriatic or hydrochloric acid.

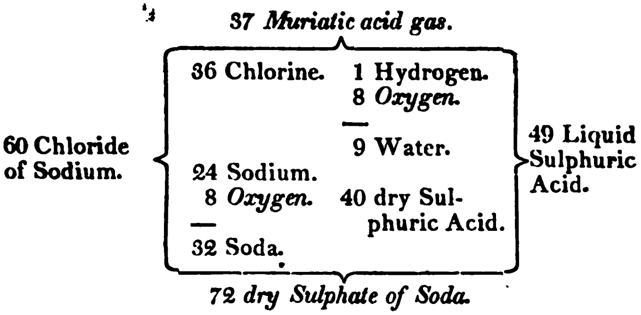
The liquid muriatic acid may also be obtained by diluting the sulphuric acid with the water necessary for the condensation of the gas, and adding the dilute acid, when cold, to the salt in the retort. To the retort an adopter may be united with the clay and sand lute, and this may terminate in a large tubulated receiver, from the aperture of which a right-angled Welter's tube is conveyed beneath a few ounces of water, contained in a two-necked bottle. A fire must then be lighted under the sand-bath, and continued as long as any liquid comes over. The adopter and receiver must be kept cool by the constant application of moistened cloths.

The proportions directed by the London College of Physicians, in their Pharmacopœia of 1824, are two pounds troy of dried chloride of sodium, 20 ounces troy of sulphuric acid, and a pint and a half of distilled water. The acid is directed to be mixed with half a pint of water in a glass vessel, and to these, when cold, the chloride of sodium is to be added. The remainder of the water is to be put into a receiver; and a retort being adapted to it, and placed in a sand-bath, the muriatic acid is to be distilled into the water, at a temperature gradually raised till the sand-bath becomes red-hot. Mr. R. Phillips finds it more convenient to mix the sulphuric acid and water in a separate vessel than in the retort; to introduce the salt first, and to pour the acid upon it; and to put less water into the receiver, and more into the retort.

If the muriatic acid, thus obtained, should contain sulphuric acid, which may be discovered by muriate of baryta occasioning a white precipitate, the acid is to be re-distilled from a fresh portion of common salt. When prepared by Woulfe's apparatus, the product in the second bottle is always perfectly pure.

The acid, formed by the process of the College, has the specific gravity of about 1.160, and 100 grains are saturated by 124 of crystallized subcarbonate of soda. That of commerce is generally about 1.156; but, by Woulfe's apparatus, and especially when the bottles are surrounded by ice or snow, it approaches the sp. gr. 1.500. The weaker acid, however, which has been mentioned (*viz.* 1.160 or thereabouts), is best adapted for keeping; for the denser kind emits a large quantity of fumes, which are extremely inconvenient in a laboratory, besides being injurious to all metallic instruments.

The theory of this process has been explained by Mr. Phillips, with the aid of the following diagram. Chloride of sodium is a compound of 36 chlorine and 24 of the metallic body sodium; liquid sulphuric acid consists of 40 parts of dry acid and 9 of water, the water being composed of 1 hydrogen and 8 oxygen. When these substances act upon each other, the water and chloride of sodium are both decomposed; 1 of hydrogen uniting with 36 of chlorine, constitute together 37 of muriatic acid gas; and 8 of oxygen with 24 of sodium form 32 of soda, which, uniting with 40 parts of dry sulphuric acid, compose 72 of dry sulphate of soda. The 37 parts of muriatic acid gas, combining with the water used to dilute the acid, rises with it in vapour, and, with the exception of a portion which always escapes, is found in the receiver in the state of liquid muriatic acid. (Phillips's Trans. of the Pharmacop. of 1824, p. 26.)



Liquid muriatic acid has the following properties:

1. It emits white suffocating fumes. These consist of muriatic acid gas, which becomes visible by contact with the moisture of the air.

2. When heated in a retort, or gas bottle, muriatic acid gas is disengaged, and may be collected over mercury.

3. Liquid muriatic acid is not decomposed by the contact of charcoal, essential oils, or other combustible bodies.

4. When diluted with water, an elevation of temperature is produced, much less remarkable, however, than that occasioned by diluting sulphuric acid; and, when the mixture has cooled to its former temperature, a diminution of volume is found to have ensued. The capacity of the diluted acid for heat Dr. Ure has found to be less than the mean capacity of the strong acid and of water, which sufficiently accounts for the increased temperature. (Ann. of Phil. x. 273.)

5. In a perfectly pure state, liquid muriatic acid is quite colourless; but it has frequently a yellowish hue. This may proceed either from a portion of chlorine or of muriate of iron, but most commonly of the latter. This colour is instantly destroyed by a few drops of muriate of tin; but this addition, instead of diminishing, obviously increases the impurity of the acid.

6. Muriatic acid combines readily with alkalies, and with most of the earths, both in their pure and carbonated states.

7. Liquid muriatic acid is specifically heavier than water. In winter, Dr. Thomson states, it may be obtained of sp. gr. 1.212. When of sp. gr. 1.203, it contains 40.659 per cent. real acid; and is constituted of 6 atoms water, and 1 atom of acid; but it can be with difficulty kept of such strength in warm weather. Its boiling point, indeed, is not higher than 107° F. when of that density. The correspondence between the specific gravity and the quantity of real acid, which liquid muriatic acid contains, is shown by the following Table, given by Sir H. Davy in his Elements of Chemical Philosophy. It is constructed from experiments made with

great care by Mr. E. Davy in the laboratory of the Royal Institution.

Table showing the Quantity of real Acid in Liquid Muriatic Acid of different Specific Gravities. (Temp. 45° Fahr. Barom. 30.)

Specific Gravity.	100 grains contain of Muriatic Acid Gas.	Specific Gravity.	100 grains contain of Muriatic Acid Gas.
1.21	42.43	1.10	20.20
1.20	40.80	1.09	18.18
1.19	38.38	1.08	16.16
1.18	36.36	1.07	14.14
1.17	34.34	1.06	12.12
1.16	32.32	1.05	10.10
1.15	30.30	1.04	8.08
1.14	28.28	1.03	6.06
1.13	26.26	1.02	4.04
1.12	24.24	1.01	2.02
1.11	22.3		

Dr. Thomson also has given the following Table, showing the specific gravities of liquid muriatic acid of different densities. Muriatic acid, he observes, composed of 1 atom acid, and 16 atoms of water, or that which contains 20.442 per cent. of real acid, seems to be the most intimate combination of acid and water; for its boiling point, according to Dalton, is a maximum, being 232°, while acid, either stronger or weaker, boils at a lower temperature. (First Princ. of Chem. i. 87.)

Table exhibiting the Specific Gravity of Muriatic Acid of determinate strengths.

Atoms of Acid.	Atoms of Water.	Real Acid in 100.	Specific Gravity.
1	6	40.659	1.203
1	7	37.000	1.179
1	8	33.945	1.162
1	9	31.346	1.149
1	10	29.134	1.139
1	11	27.206	1.1285
1	12	25.517	1.1197
1	13	24.026	1.1127
1	14	22.700	1.1060
1	15	21.512	1.1008
1	16	20.442	1.0960
1	17	19.474	1.0902
1	18	18.590	1.0860
1	19	17.790	1.0820
1	20	17.051	1.0780

According to Mr. Faraday (on Chemical Manipulation, sect. 606,) if we multiply by 0.74 the number of grains of marble dissolved by any given quantity of muriatic acid, the product will show the number of grains of dry or real acid, by which the carbonate of lime has been dissolved.

8. When liquid muriatic acid is brought into contact with any substance containing oxygen in a state of loose combination, the hydrogen of the acid unites with the oxygen, and forms water, while the chlorine is liberated in a gaseous state. It is in this way that chlorine is procured for the purposes of chemistry and the arts; but, instead of liquid muriatic acid, it is usual to substitute materials capable of furnishing the acid gas, (*viz.* common salt, sulphuric acid, and oxide of manganese,) as already described in the chapter on chlorine.

On the Theories which have prevailed respecting Chlorine and Muriatic Acid.

There are few subjects, respecting which the opinions of chemists have undergone such frequent changes, as concerning the nature of chlorine and of muriatic acid. The view originally taken by Scheele, the illustrious discoverer of the former substance, was, that the muriatic acid is compounded of a certain base and an imaginary principle called *phlogiston;* and that by the action of certain bodies it became *dephlogisticated*, or deprived of that supposed principle of inflammability. (On Manganese, sect. xxiii. xxiv.) It was afterwards found, however, that all bodies, which are capable of producing this change in muriatic acid, contain oxygen, and that their proportion of oxygen is diminished by the process. It appeared, therefore, to be an obvious conclusion, that what takes place in the action of metallic oxides on muriatic acid is simply the transference of oxygen from the oxide to the acid; and, conformably with this theory, the resulting gas received the name of *oxygenated muriatic* or *oxymuriatic acid.* Sir H. Davy was led, by his earlier experiments, to modify, in some degree, this view of the theory of the process; and to consider the muriatic acid as a compound of a certain basis with water, and the oxymuriatic as a compound of the same basis with oxygen. This modification was suggested by the fact, that when a metallic oxide is heated in muriatic gas, oxymuriatic acid is obtained, and water appears in a separate state. It was evident, therefore, that muriatic acid gas must either contain water ready formed; or the elements of water; or hydrogen, capable of composing water with the oxygen of the oxide. But, at a subsequent period, the same distinguished philosopher was induced, by the experiments of Gay Lussac and Thenard, as well as by his own researches, to form a different theory on the subject, and to regard the so called oxymuriatic acid as a simple or undecompounded substance; and muriatic acid as a compound of that simple substance with hydrogen. To convert the muriatic acid into chlorine, we have only, according to this view, to abstract hydrogen from the muriatic acid; and this, it is believed, is all that is effected by the action of those metallic oxides, which are adapted to the purpose. Again, to convert chlorine into muriatic acid, we have only to combine it with hydrogen; and accordingly the simple mixture of one measure of each of those gases, when exposed for a short time to the sun's rays, or exploded by an electric spark, affords two measures of muriatic acid gas.

Chlorine (as Sir H. Davy proposed to call it, in order to avoid all connexion of its name with hypothetical views) is now universally admitted to unite at once with the metals, without requiring, like the sulphuric, nitric, and other acids, that the metals should first be in the state of oxides. In proof of this, it is sufficiently established, that no oxygen can be obtained either alone, or in a state of combination with combustible bodies added for the purpose, from perfectly pure compounds of chlorine and metals. The analyses, however, of the metallic muriates, as they were formerly considered, remain unimpeached by this change of theory. All that is necessary to transmute in idea a muriate into a compound of chlorine, is to deduct the oxygen from the metallic oxide; and, adding it to the muriatic acid, to consider the sum as chlorine. For example, muriate of soda, deprived of all water, consists,

On the old theory, of muriatic acid			46.7	28
Soda composed of	Oxygen	13.3	53.3	32
	Sodium	40.0		
			100.	60

On the new theory, chloride of sodium consists of

Sodium	40	24
Chlorine	60	36
	100	60

On the discarded theory of oxymuriatic acid, that supposed compound was stated to be constituted of 3 volumes of muriatic acid gas + 1 volume of oxygen condensed into 2 volumes, and by weight of

Oxygen	22.22	8
Muriatic acid	77.78	28
	100.	36

According to this view, the atom of dry muriatic acid, (hydrogen being unity, and oxygen 8,) would be equivalent to 28; and this + 8 (1 atom of oxygen) would give 36 for the atom of oxymuriatic acid. The latter number, indeed, still represents the atom of chlorine, as deduced from the fact that it unites with an equal volume of hydrogen gas, and is 36 times specifically heavier than that inflammable gas. We may consider, then, 60 parts of common salt as composed of 28 parts dry muriatic acid and 32 parts of soda (= 24 sodium and 8 oxygen), according to the old view; or of 24 sodium + 36 chlorine, according to the new theory.

It is remarkable that there is hardly any fact, connected with the chemical history of chlorine and muriatic acid, that does not admit of being almost equally well explained upon the hypothesis that

rine is a compound, as upon that of its being a simple substance.
he whole, however, the weight of evidence is decidedly in fa-
of the new, or rather the revived opinion of its elementary na-
especially since the discovery of iodine; and I have no scruple,
:fore, in adopting it, as affording the most simple and satis-
ry explanation of phenomena, as well as the best ground-work
perspicuous arrangement of the objects of chemistry.*

ART. 3.—*Hydrogen with Iodine.—Hydriodic Acid.*

ıe affinity of iodine for hydrogen is very strong, and it unites
hydrogen gas, and detaches hydrogen from several of its com-
.ions, affording, as the result, a distinct and well characterized

iodine be heated in dry hydrogen gas, an expansion of volume
ı place; an acid gas is formed, which is very absorbable by
r, and acts so much on mercury that it cannot be preserved
over that metal. A similar gaseous compound is formed by
sing iodine to sulphuretted hydrogen gas. But the acid gas
st prepared in quantity, by the action of 16 parts of moistened
ıe and 1 part of phosphorus on each other, the mixture being
lled in a retort. The gas may be received into a vessel filled
common air, which it expels by its superior gravity. Gay
ıac recommends, instead of a retort, a small bent tube, which,
putting the iodine into it, is to be inverted over mercury; the
hich it contains is to be expelled by a glass rod, that almost
.ts capacity; and the phosphorus is to be brought into contact
the iodine, by introducing it through the mercury. As soon
e contact takes place, the acid gas is disengaged, and may be
cted by putting the open end of the tube under a glass jar
ling inverted in mercury.

ırcet recommends another process as greatly preferable for ob-
ng hydriodic acid gas. It is founded on the property which
.e has of decomposing, at a gentle heat, one part of the water
.e hypophosphorous acid, and attracting its hydrogen, at the
: time carrying the phosphorus to its maximum of oxidation.
this purpose the acid must be carefully heated just to the point
e it allows phosphuretted hydrogen to escape from it, and
e it contains no more water than is essential to its composition.
then poured, thus concentrated, into a small tube, and an equal
ht of iodine is added. By a gentle heat, hydriodic acid gas
oduced abundantly, *viz.* in the proportion of about 12 cubic
:s from every 10 grains of acid, and of such purity as to be en-
absorbable by water. (Ann. de Ch. et de Phys. xxxvii. 220.)
ɔ sooner does the hydriodic acid gas come into contact with

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*he reader who wishes to examine fully the evidence for both opinions, is
ed to the controversy between Drs. Murray and J. Davy, in the 34th volume
cholson's Journal; to Sir H. Davy's paper in the Phil. Trans. for 1818, p.
to the 8th volume of Trans. of the Royal Society of Edinburgh; the An-
f Philosophy, xii. 379, and xiii. 26, 285; and to a paper by Mr. R. Phillips,
: new series of that work, vol. i. p. 27, on the action of chlorides on water.

mercury, than it begins to be decomposed; and, if the contact be prolonged a sufficient time, or agitation be used, the decomposition is complete. The iodine unites with the mercury; and there remains hydrogen gas, in volume exactly one half that of the acid gas. It is decomposed, in a similar manner, by all metals, except gold and platinum.

The acid gas is colourless, its taste is very sour, and its smell resembles that of muriatic acid gas. Its specific gravity was found by experiment to be 4.443; by calculation it should have been 4.428. Compared with hydrogen, its specific gravity is 62.5 to 1. 100 cubic inches weigh 133.6 grains.

The acid gas is rapidly decomposed by being heated in contact with oxygen gas, which detaches the hydrogen. Chlorine also instantly deprives it of hydrogen, and produces muriatic acid gas; and the iodine re-appears in the form of a beautiful violet vapour. When mixed with proto-phosphureted hydrogen, both gases are condensed into white cubical crystals, which are volatilized at a moderate heat without fusion or decomposition. (6 Ann. de Chim. et Phys. 305.) The acid gas is composed, by weight, according to Gay Lussac, of 100 iodine and 0.849 hydrogen; but, correcting the specific gravity of hydrogen gas to 0.0694, its true composition will be, by weight,

Hydrogen - - - - - - -	1
Iodine - - - - - - - - -	125
Weight of its atom - - -	126

Taking the specific gravity of the vapour of iodine at 8.6111, and that of hydrogen at 0.0694, Dr. Thomson makes the sp. gr. of hydriodic gas the mean of those two numbers, or 4.34027; and its atomic weight he fixes at 15.625, equivalent to 125 on the hydrogen scale.

Hydriodic Acid Gas is plentifully absorbed by water; the solution is fuming, and has the density of 1.7. To prepare this liquid in quantity, Gay Lussac recommends to put powdered iodine into water, and to pass sulphureted hydrogen gas through the mixture. The hydrogen unites with the iodine, and the sulphur is precipitated; but, according to Serrulas (Ann. de Ch. et de Phys. xx. 163), not completely. The liquid may be concentrated by evaporation. Till it attains the temperature of 257°, water only distils; above this point, the acid itself is volatilized, and remains stationary at 262½°, its density being then 1.7.

The liquid acid is slowly decomposed by contact with air, its hydrogen being attracted by the oxygen of the atmosphere, and a portion of iodine liberated, which gives the liquor a colour, of intensity proportionate to the quantity of free iodine. Concentrated sulphuric acid, nitric acid, and chlorine, decompose it, and separate iodine. With solutions of lead, it gives a fine orange precipitate; with a solution of peroxide of mercury, a red one; and with silver, a white precipitate, insoluble in ammonia.

When submitted to galvanic electricity, the liquid hydriodic acid is rapidly decomposed; iodine appears at the positive, and hydron at the negative pole. It dissolves zinc and iron, with a disen- gement of hydrogen gas, which proceeds from the water. It has action on mercury, though the gas so powerfully affects that etal. It is decomposed by those oxides, which hold their oxygen osely, and combines with the rest, forming a genus of neutral lts, called *hydriodates.* Of these salts, that with base of potassa rives some importance from its use in medicine. A process for eparing it advantageously is described in the Ann. of Phil. N. vii. 468.

In general the hydriodates are readily soluble in water. Those potassa and baryta are not decomposed by heat, except oxygen in contact with them; the salt with base of lime is wholly, and at with base of magnesia partially, decomposed at high tempe- tures.

ART. 4.—*Hydrogen with Bromine.—Hydro-bromic Acid.*

The analogy between the action of chlorine and of bromine on ganic matters led M. Balard to suspect an analogy between the uses of these phenomena, and to direct his attention towards the covery of a compound of bromine and hydrogen. These two bstances do not act upon each other, when bromine is exposed to drogen gas; but, when bromine is brought into contact with some the gaseous compounds of hydrogen, a colourless gas is obtain- , strongly acid, absorbable by potassa, and capable of reproduc- the cubic crystals already described. These, heated with strong lphuric acid, afford a gas, which is *hydro-bromic acid.* From this s chlorine throws down vapours of bromine; and certain metals o, by attracting bromine, liberate hydrogen gas.

Hydro-bromic acid is not producible even by exposing the va- ur of bromine and hydrogen to the solar rays; but it is generat- by exposing the mixture to the flame of a taper, and still better introducing an ignited iron rod into the bottle containing it. e combination does not, as with chlorine, extend rapidly through mass, but only round the heated body which has excited it.

Hydriodic acid, and sulphureted and phosphureted hydrogen ses, are decomposed by bromine, and hydro-bromic acid is gene- ed, with a disengagement of heat. Hydriodic acid gas, decom- sed by bromine, undergoes no change of volume; but the com- unds of hydrogen with sulphur and phosphorus are both expand- in volume.

The hydro-bromic acid, when obtained from the crystals that re- t from the direct action of potash on the ethereal solution, (see 207,) is contaminated with sulphurous and hydrochloric acids. procure it pure, a process may be employed analogous to that d for hydriodic acid gas. Bromine and phosphorus, placed in tact, and moistened with a few drops of water, afford abundantly gas, which is *hydro-bromic acid*, and which is permanent over rcury.

This gas has the following properties:

It is colourless; its taste is intensely acid; by contact with atmospheric air, it gives white vapours, more dense than those produced by hydro-chloric acid under the same circumstances. These vapours have a pungent smell, and excite cough.

It is not altered by transmission through a red-hot glass tube, either alone or mixed with oxygen gas, nor is that mixture acted upon by introducing a burning taper into it.

It is not, like chlorine, capable of decomposing water, neither oxygen nor hydro-bromic acid being produced by transmitting bromine and aqueous vapour through a red-hot tube.

Hydro-bromic acid is decomposed by chlorine, which instantly liberates abundant vapours, that condense into drops of bromine.

When pure, mercury does not appear to act upon the acid gas; but tin and potassium produce an entire decomposition; the first at a temperature a little elevated, the second at common temperatures. In the latter case, a volume of hydrogen remains rigorously equivalent to half that of the original gas. Hence it is formed, analogous to hydriodic and hydro-chloric acids, of equal volumes of bromine and hydrogen without condensation.

Hydro-bromic acid is very soluble in water, which, by absorbing the gas, increases in volume, acquires great density, and also the property of emitting white vapours by contact with the air. It is colourless, unless the gas is mixed with vapours of bromine, of which the acid is capable of taking up an excess. The coloured acid may be decoloured by heat, but it is then reduced in density.

Chlorine decomposes liquid hydro-bromic acid, and imparts to it the same colour as an excess of bromine.

Nitric acid acts upon hydro-bromic acid, at first moderately, but with decided energy as soon as its action has commenced. The result is a liquid which, like aqua regia, dissolves gold and platinum.

Concentrated sulphuric acid has, to a certain degree, the property of decomposing hydro-bromic acid, and of liberating bromine mixed with sulphurous acid.

Certain metals (iron, zinc, tin,) act upon the liquid acid with a disengagement of hydrogen gas.

The greater part of the oxides, *viz.* the alkalies, earths, oxides of iron, deutoxides of copper and mercury, form liquid combinations, which may be regarded as hydro-bromates.

Some oxides (of lead and silver for instance) give rise to a double decomposition, producing water and metallic bromides.

Other oxides, containing much oxygen, decompose a part of the hydro-bromic acid; and the remainder, uniting with the oxide, constitutes a hydro-bromate or metallic bromide. Such are deutoxide and tritoxide of lead, and peroxides of antimony and manganese.

The affinity of bromine for hydrogen is less than that of chlorine, but greater than that of iodine. Hydrogen easily unites with chlorine; more difficultly with iodine and bromine. Hydro-bromic acid is decomposed by chlorine, but bromine, in its turn, decomposes hydriodic acid.

The action of metals on these acids exhibits similar differences.

Hydriodic acid is decomposed by contact with mercury. Pure hydro-bromic acid, on the contrary, may be kept some time unaltered in contact with that metal.

Hence the properties of hydro-bromic acid appear to hold a middle place between those of hydro-chloric and hydriodic acids.

ART. 5.—*Hydrogen with Fluorine.—Hydro-fluoric Acid.*

Though it has not yet been demonstrated that hydrogen is the acidifying principle of this acid, yet there appears every reason to believe that in the same manner as hydro-chloric acid is constituted of chlorine united with hydrogen, this acid also consists of a peculiar base, belonging, like chlorine, to the electro-negative class of bodies, and rendered acid by combination with hydrogen. To this basis, though not yet exhibited in a separate state, the name of *fluorine* has been given, and the acid has been termed *hydro-fluoric.*

Hydro-fluoric acid may be obtained in a liquid state by distilling powdered fluor spar, (a mineral found abundantly in Derbyshire,) with twice its weight of strong sulphuric acid. A leaden (or in preference a silver) retort and receiver must be used; to the first a moderate heat must be applied, and the receiver must be surrounded by pounded ice or snow. An ingenious apparatus for this purpose is described and represented by Mr. Knight, in the 17th vol. of the Philosophical Magazine.

When the liquid acid is obtained, it must be preserved in leaden or silver bottles, with air-tight stoppers of the same material. Its volatility, however, is such, that it is difficult to confine it. Its specific gravity was found by Sir H. Davy to be 1.0609, but it is increased by the gradual additions of water to 1.25, a property observed in no other liquid. When suddenly mixed with water, it becomes very hot, and enters into ebullition. Applied to the skin, it raises painful pustules, or, if in sufficient quantity, occasions deep and dangerous ulcers. It emits very penetrating and noxious vapours, and acts strongly on glass, destroying the polish of its surface, and corroding it deeply. Hence it has been used for etching on glass. According to Professor Silliman, it is, however, better adapted for etching, when diluted with three or four parts of water, than in a concentrated form. Plates of glass, covered with a composition of bees' wax and turpentine, and surrounded by a rim of the same substance, have those parts which are denuded by the graver perfectly etched in the course of a minute or two. (Amer. Journ. vi. 354.)

When brought into contact with potassium, a violent detonation ensues, and hydrogen gas is disengaged, a solid white substance being at the same time formed. Fluoric acid, it is remarked by Berzelius, is distinguished by its great capacity of saturation; for 100 parts combine with a quantity of base containing 74.72 parts of oxygen, and the compound is then neutral. Many of its salts are readily soluble; but they cannot be obtained quite neutral in a solid form, being found in that state to have an excess of one or other ingredient. Its compounds with alkalies crystallize with an excess of acid, and attack glass; hence they can only be prepared in silver or platinum vessels. It is extremely difficult to obtain them quite free from silica.

Fluoric acid is also distinguished by the property of forming, with acids weaker than itself, compounds in which the latter serve as a kind of base. These compounds undergo partial decomposition, and deposit a portion of their base, when merely added to water. Fluoboric and fluosilicic acids belong to this class, and Berzelius has added others to the number.

The *atomic weight* of fluoric acid has been investigated by Dr. Thomson, who has satisfied himself that it is 10. This number is assigned to it on the supposition that the fluates are compounds of fluoric acid with metallic oxides. But a different view of these compounds may be taken, and we may consider them, with M. Ampère and Sir H. Davy, as compounds of *metals* with a peculiar principle analogous to chlorine, which it has been proposed to call *fluorine*. Fluor spar, for example, may be either a *fluate of lime*, or a *fluoride of calcium*. And in the same manner that we convert, in imagination, a muriate into a chloride, we may change a fluate into a fluoride. Thus fluor spar may be constituted either of

1 atom of fluoric acid		10
1 atom lime	20 calcium 8 oxygen	28
Weight of the atom of anhydrous fluate of lime		38

or it may consist of

1 atom of fluorine (10 + 8)	18
1 atom calcium	20
Weight of the atom of fluoride of calcium	38

It should be added, that, if the latter view be correct, fluates, like muriates, can only be capable of existing either in solution, or in the state of hydrous salts. The actual conversion of a fluoride into a fluate will then be attended with the decomposition of an atom of water; and 1 of hydrogen, by weight, will unite with 18 of fluorine, making the real atomic weight of fluoric acid 19, while 8 of oxygen will unite with the atom of metallic base. The atomic weight of the fluate will, in that case, be 19 + that of the alkaline or earthy base, or 9 (= to an atom of water) more than the number assigned to the anhydrous compound. At present the existence of fluorine is supported only by analogy; an analogy, however, strengthened by the fact, discovered by Kuhlman, that fluor spar gives no fluoric acid, when acted upon by that species of sulphuric acid, which contains essentially no water. (Ann. de Ch. et de Phys. Feb. 1827.)

In the chapter on silica, it will be shown that fluoric acid unites with that earth, and composes a permanent gas. It does the same with boracic acid; and Berzelius has investigated a new class of compounds, discovered by him to consist of hydrofluoric acid with the titanic, columbic, tungstic, and molybdic acids. (Ann. de Ch. &c. xxix. 295, 336.)

SECTION II.

On Nitrogen or Azote.

After separating, from any quantity of atmospherical air, all the oxygen which it contains, there remains a gas which was called by Lavoisier *azotic gas*, a name applied to it in consequence of its unfitness for supporting animal life, and derived from the Greek privative α and ζωὴ *vita.* This, however, as being merely a negative property, has since been deemed an improper foundation for its nomenclature, and the term NITROGEN gas has been substituted; because one of the most important properties of its base is, that by union with oxygen it composes nitric acid. By this appellation, therefore, I shall hereafter distinguish it.

I. Nitrogen gas may be procured, though not absolutely pure, yet sufficiently so for the purpose of exhibiting its general properties, in any of the following manners: 1. Mix equal weights of iron filings and sulphur into a paste with water, and place the mixture, in a proper vessel, over water, supported on a stand; then invert over it a jar full of common air, and allow this to stand exposed to the mixture for a day or two. The air contained in the jar will gradually diminish, as will appear from the ascent of the water, till at last only about four-fifths of the original volume of the air will remain. The vessel containing the iron and sulphur must next be removed, by withdrawing it through the water; and the remaining air may be made the subject of experiment.

2. A quicker process, for procuring nitrogen gas, consists in pouring into a bottle, about one-fourth its capacity of the solution of nitrous gas in liquid sulphate of iron, or of liquid sulphuret of lime, and agitating it with the air which fills the rest of the bottle. During the agitation, the thumb must be firmly placed over the mouth of the bottle; and, when removed, the mouth of the bottle must be immersed in a cup full of the same solution, which will supply the place of the absorbed air. The agitation, and admission of fluid, must be renewed, alternately, as long as any absorption takes place.

3. Atmospheric air, also, in which phosphorus has burned out, affords, when time has been allowed for the condensation of the phosphoric acid, tolerably pure nitrogen gas.

4. Azotic gas may be procured from the lean part of flesh meat (beef for example), which may be put into a gas bottle, along with very dilute nitric acid. By a heat of about 100°, the gas is disengaged, and may be collected over water. Its source has been satisfactorily traced to the animal substance, no part of it proceeding from the nitric acid.

5. It may be obtained by the action of chlorine on ammonia, in a manner which will be afterwards described in speaking of that alkali.

II. Nitrogen gas has the following properties:

1. It is not absorbed by water.

2. *It is a little lighter than atmospheric air*, 100 cubic inches being found by Sir H. Davy to weigh 30.04 grains under a pressure of 30 inches, and at the temperature of 55° Fahrenheit. At 60° Fahrenheit 100 inches weigh, therefore, 29.73 grains. According to Biot and Arago, its specific gravity is 0.96913. Dr. Thomson makes it 0.9722; and Berzelius and Dulong 0.9760.

3. It immediately extinguishes a lighted candle, and all other burning substances. Even phosphorus, in a state of active inflammation, is instantly extinguished when immersed in nitrogen gas. This is best shown by placing the burning phosphorus in a tin cup, raised by a stand over the surface of the water, and quickly inverting over it a jar filled with nitrogen gas.

4. It is fatal to animals that are confined in it.

5. When mixed with pure oxygen gas, in the proportion of four parts to one of the latter, it composes a mixture resembling atmospheric air in all its properties. Of this any one may be satisfied, by mixing four parts of azotic gas with one of oxygen gas, and immersing, in the mixture, a lighted taper. The taper will burn as in atmospherical air.

Composition of Nitrogen.

That nitrogen is not an element, but itself a compound, has been long suspected, and various attempts have been made to discover its ingredients. Berzelius, from the combination of experiment with much theoretical reasoning, has deduced, that nitrogen is compounded of oxygen and an unknown base. (2 Thomson's Annals, 284.) This base, it must be observed, however, is purely hypothetical; and, as it has never yet been exhibited in a separate state, we cannot at present know any thing of its properties. Berzelius has proposed for it the name of *nitricum*.

The experiments of Sir H. Davy, directed to the decomposition of nitrogen, on the presumption of its being an oxide, were not attended with any better success. (Phil. Trans. 1810.) Potassium was ignited, by intense Voltaic electricity, in nitrogen gas; and the result was, that hydrogen appeared, and some nitrogen was found deficient. This, on first view, would lead to the suspicion that nitrogen had been decomposed. But, in subsequent experiments, in proportion as the potassium was more free from a coating of potassa, which would introduce water, so, in proportion, was less hydrogen evolved, and less nitrogen found deficient. The general tenor of these inquiries, therefore, lends no strength to the opinion that nitrogen is a compound body.

ART. I.—*Nitrogen with Oxygen.—Atmospheric Air.*

The atmosphere is a collection of elastic fluids, retained on the surface of the earth by their gravitation. Its weight was first ascertained by Galileo, and applied by Toricelli to explain the rise of water in pumps, and of mercury in barometrical tubes; and by Paschal to the mensuration of the height of mountains. At the level of the ocean it is adequate to sustain a column of water having the altitude of 34 feet, or one of mercury of the height of 30 inches, and it presses with the weight of about 15 pounds on every square inch of surface. As we ascend, the atmosphere decreases in density in a geometrical proportion to equal ascents. Thus at three miles in height, the density of the atmosphere is one half what it is at the earth's surface, or equal to a column of 15 inches of mercury; at six miles, the barometer would stand at ¼ the usual height, or at 7½ inches; at nine miles of elevation, at 3¾ inches; and 15 miles high nearly at 1 inch. Hence the greatest part of the atmosphere is always within 15 or 20 miles of the earth's surface; though from the refraction of the sun's light, it may be inferred to extend from 40 to 45 miles in height. Beyond the former limit it appears highly probable, from the observations of Dr. Wollaston, (Phil. Trans. 1822) that our atmosphere does not reach at all; the force of gravity downwards, upon a single particle, being there equal to the resistance arising from the repulsive force of the medium. We have no evidence of the existence of similar matter round any other planet; and it has been ascertained, by the observations of Captain Kater, that no retardation of the motion of Venus can be perceived in her progress towards the sun, as would happen if he were encompassed by a refracting atmosphere. The approach also of Jupiter's satellites to the body of the planet round which they revolve, is uniformly regular, till they appear in actual contact, showing that there is not that extent of atmosphere, which Jupiter should attract to himself from an infinitely divisible medium filling all space. These observations are favourable, as Dr. Wollaston remarks, to the existence of particles of matter no longer divisible, for if an elastic fluid like our atmosphere consist of such particles, we can scarcely doubt that all other bodies are similarly constituted; and may without hesitation conclude that those equivalent quantities, which we have learned to appreciate by proportionate numbers, do really express the relative weights of elementary atoms, the ultimate objects of chemical research.

The cause, which supports in a vaporous or gaseous state bodies that exist in that state at the temperature of the atmosphere, is, according to an ingenious speculation of Mr. Faraday, (Phil. Trans. 1826.) the elastic force of their particles, or their mutual repulsion, depending probably on their atmospheres of heat. This force is restrained by two causes—incumbent pressure, and gravity. When the first is removed, or supposed to be removed, as by a gradual ascent into the higher regions of the atmosphere, we shall come at length to a point where the two forces of gravity and elasticity will be exactly *in equilibrio*. At that point no tendency will exist in the particles to fly farther asunder; and therefore there will be a limit, beyond which vaporous matter of that kind cannot exist.

But there are bodies, which are gaseous at high temperatures only; and below a certain point, seem incapable of forming vapour. This is the case with silver heated below a white heat, of mercury during winter, and of oil of vitriol at common temperatures. In such bodies, the aggregative attraction of their particles, apart from general gravitation, seems to have a tendency to prevent the formation of vapour, and to condense it when formed. Thus a lump of camphor at one end of a sealed glass tube, the other end of which is kept cool, deposits one or two small crystals, which increase in size, while no deposit takes place on the glass.

These causes, Mr. Faraday apprehends, are quite sufficient to set a limit to evaporization, and effectually to prevent the volatilization of the earths and metals, which have been imagined by some persons to enter into the composition of our atmosphere.

The great body of air, constituting our atmosphere, is in a state of constant motion, not only from its accompanying the earth in its rotation round its axis, but because it flows also from the equator towards the poles, and contrariwise. Over the torrid zones, the air is expanded by heat, and acquires a tendency to ascend, while the air from the temperate and frigid zones presses forward to supply the vacancy. In the torrid zones, the upper regions of the atmosphere meet with less lateral pressure than is necessary to support them, and the air, therefore, overflows in both directions, so that currents northward and southward are established in the higher regions of the atmosphere. Thus a constant circulation is maintained, and a cause is established for supporting a temperature on the earth's surface, approaching much more nearly to uniformity, than it could have been without such a provision of nature.

It has already been stated that the air of our atmosphere, besides small proportions of aqueous vapour and carbonic acid, is principally constituted of two different gases, *viz.* oxygen gas, and azotic or nitrogen gas, the former of which seems to be the only ingredient on which the effects of the air, as a chemical agent, depend. Hence combustible bodies burn in atmospheric air, in consequence of the oxygen gas which it contains; and, when this is exhausted, air is no longer capable of supporting combustion.* Its analysis is most satisfactorily demonstrated by the action of heated mercury, as was first effected by Lavoisier in the following manner.

Into a small matrass, capable of holding from 45 to 50 cubical inches, pour about 1500 grains of mercury, and let its neck be so bent that its extremity may open into a known quantity of atmospheric air confined in a glass receiver over mercury. (See the cut in the following page.) The receiver should not be more than one-third full of air, in order to allow space for its expansion by heat; and the body of the matrass must be surrounded by dry sand, contained in the sand pot of a distilling furnace. The vessels being thus disposed, a fire is to be lighted in the furnace, and kept up for several days, so as to maintain the quicksilver nearly at the boiling point, which is thus freely exposed to the air in the bell, as well as to that in the matrass. At first, the air is rarefied by heat; but when the fire has been supported for two or three days, its volume begins to diminish, and at the end of the fifth day, when the vessels have cooled, it is found that about one-sixth the bulk of the original air has disappeared. What remains is completely altered in its properties. It immediately extinguishes flame, and is fatal to any small animal that may be inclosed in it. The mercury, also, may be observed to have undergone a change; and scaly particles of a flea colour may be seen floating on its surface.

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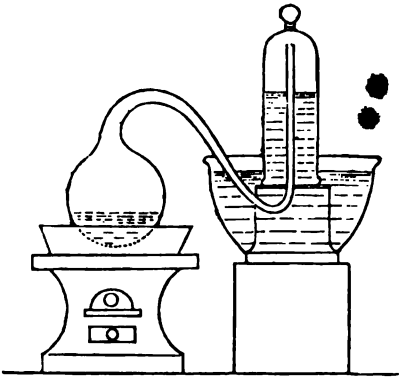
* Certain combustible bodies even cease to burn in atmospheric air long before its oxygen is consumed, for reasons that will hereafter be given.



When these particles are collected, and subjected to a heat approaching to redness, in a coated glass tube, a quantity of gas may be collected by a proper apparatus, the volume of which will be found equivalent to that which has disappeared. Its properties, when examined, answer to those of oxygen gas, which is thus decisively proved to be a constituent part of the air of our atmosphere, the other ingredient of which is shown to be an elastic fluid incapable either of supporting combustion or animal life. The analysis, however, effected in this way, is not adequate to disclose the true proportion of the gases constituting the atmosphere, for mercury has not a sufficiently strong attraction for oxygen to separate the whole of that existing in the air, which amounts to about one-fifth of the whole volume. This separation may be completely effected by other methods to be presently described, which prove that atmospheric air is composed of about one volume of oxygen gas and four of nitrogen, besides small proportions of carbonic acid and aqueous vapour, the latter varying with the temperature.

This process is extremely tedious; but evidence of the nature of atmospheric air may be obtained much more expeditiously by the following experiments.

Burn phosphorus, in the manner described, page 189, substituting, for oxygen gas, common atmospherical air. The combustion will, in this instance, be less vivid; will cease sooner; and the absorption, when the vessels have cooled, will be much less considerable than in the former case. The phosphorus, however, will have absorbed the whole of the oxygen gas contained in the air submitted to experiment; and hence it may be employed for measuring the quantity of oxygen gas in a given bulk of atmospherical air. This may be accomplished either by its slow or rapid combustion. Berthollet proposes to expose a cylinder of phosphorus, fastened to a glass rod, in a narrow glass vessel, graduated into equal parts, and standing full of air over water. (See fig. 24.) The phosphorus immediately begins to act, without visible combustion, on the included air; and in six or eight hours its effect is completed. The residuary azotic gas has its bulk enlarged about one-40th, by absorbing a little phosphorus; and for this, allowance must be made in measuring the diminution. (Annales de Chimie, xxiv. 78.)

In the eudiometer of Seguin, the rapid combustion of phosphorus is employed with the same view. A glass tube, open at one end only, about an inch in diameter, and eight or ten high, is filled with, and inverted in, mercury. A small bit of phosphorus, dried with blotting paper, is then introduced, and, by its inferior specific gravity, rises to the top of the tube where it is melted, by bringing a red-hot poker near to the outer surface of the glass. When the phosphorus is liquefied, a measured portion of the air to be examined is admitted, by a little at once, into the tube. The phosphorus inflames at each addition, and the mercury rises. When all the air under examination has been added, the red-hot poker is again applied to insure the completion of the process, and the residuary gas is transferred into a graduated measure, where its bulk is carefully ascertained. In this instance, about one-40th the volume of the residuary gas is to be deducted from the apparent quantity of azotic gas, because, in this case also, a small portion of phosphorus is dissolved by the latter, and occasions a trifling expansion. With this deduction, atmospheric air loses pretty accurately 21 parts out of every 100; and contains, therefore, 21 *per cent.* of oxygen, and 79 of azote by measure.* It is remarkable, that no appreciable difference exists between the proportions of oxygen and azote in the atmospheres of distant places, from which it appears, that the purity and salubrity of air depend on some other circumstances than the proportion of these its chief elements.

The inferior fitness of atmospherical air to that of oxygen gas, for supporting combustion, may be shown, also, by a comparative experiment with two candles. A wax taper may be suffered to burn in a jar of atmospheric air over water, till it is extinguished; and the duration of its burning, and the diminution it occasions in the air, are to be noted. When the combustion is repeated in a like quantity of oxygen gas, it will be found to last considerably longer, and the diminution of volume in the gas will be much greater.

Of the fifty-two simple or elementary bodies, ten only are incapable of being acted upon at any temperature by the oxygen present in atmospheric air. These are chlorine, iodine, bromine, azote, silver, gold, platinum, rhodium, palladium, and iridium. All the rest absorb oxygen from the atmosphere, either at the ordinary temperature, or at a more elevated one which differs for different individuals.

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* Various other methods of analyzing atmospherical air will be described in the course of the work, references to which may be found in the Index, under the head *Eudiometer*

Take two tubes, each a few inches long, closed at one end, and divided into 100 aliquot parts. Fill the one with atmospherical air, the other with oxygen gas, and invert them in two separate cups containing a solution of hydrogureted sulphuret of potassa, which has been made with cold water, and been shaken in a bottle partly filled with the solution, and partly with atmospheric air, a precaution recommended by Gay Lussac and Humboldt. The liquid will ascend gradually within the tube of common air, till, after a few days, about four-fifths of its original volume will remain; but in that containing oxygen, it will ascend much higher, and if the gas be pure, will even absorb the whole.

The explanation of this fact is, that the solution has the property of absorbing oxygen, but not nitrogen. It therefore acts on atmospheric air, only as long as any oxygen gas remains, and it may be employed as a means of ascertaining the quantity of this gas in the atmosphere at different times, and in distant places. An instrument, for applying this eudiometrical liquor, was invented by Guyton. (Nicholson's Journal, 4to, i. 268, and Phil. Mag. iii. 171.) But an apparatus, of much greater simplicity, and facility of application, is that of Professor Hope of Edinburgh, announced in Nicholson's Journal, 8vo. iv. 210. It consists of a small bottle, of the capacity of 20 or 24 drachms (fig. 20, pl. ii.), destined to contain the eudiometric liquid, and having a small stopper at *b*. Into the neck of the bottle a tube is accurately fitted by grinding, which holds precisely a cubic inch, and is divided into 100 equal parts. To use the apparatus, the bottle is first filled with the liquid employed, which is best prepared by boiling a mixture of quicklime and sulphur with water, filtering the solution, and agitating it for some time in a bottle half filled with common air. The tube, filled with the gas under examination (or with atmospherical air, when the quality of this compound is to be ascertained), is next to be put into its place; and, on inverting the instrument, the gas ascends into the bottle, where it is to be brought extensively into contact with the liquid by brisk agitation. An absorption ensues; and, to supply its place, the stopper *b* is opened under water, a quantity of which rushes into the bottle. The stopper is replaced under water; the agitation renewed; and these operations are performed alternately, till no further diminution takes place. The tube *a* is then withdrawn, the neck of the bottle being under water, and is held inverted in water for a few minutes; at the close of which the diminution will be apparent. Its amount may be measured by the graduated scale engraved on the tube.

To the eudiometer of Dr. Hope there are, however, a few objections. If the tube *a* and the stopper *b* are not both very accurately ground, air is apt to make its way into the instrument to supply the partial vacuum, occasioned by the absorption of oxygen gas. This absorption causes a diminished pressure within the bottle; and, consequently, towards the close of each agitation, the absorption goes on very slowly. Besides, the eudiometric liquid is constantly becoming more dilute, by the admission of water through *b*. To obviate all these difficulties, I have substituted for the glass bottle one of elastic gum, as shown by fig. 21, *b*. The tube *a* is accurately ground into a short piece of very strong tube of wider bore, as shown at *c*, the outer surface of which is made rough by grinding, and shaped as represented, that it may more effectually retain the neck of the elastic bottle when fixed by waxed thread. This instrument is used, in every respect, in the same way as Dr. Hope's. The only difficulty is in returning the whole of the residuary gas into the tube; but the art of doing this will be readily acquired by practice.

An ingenious modification of this eudiometer, which enables us to measure an absorption of only $\frac{1}{1000}$th part of the gas employed, is described by Mr. Pepys in the Philosophical Transactions for 1807, or Philosophical Magazine, xxix.

Another method of determining the composition of atmospherical air, is by means of combustion with a known volume of hydrogen gas; for, as it is well ascertained that one-third of the diminution, on firing hydrogen and oxygen gases, is owing to the condensation of the latter, we have only to observe very correctly the contraction of volume. This is best done by means of an instrument called VOLTA'S EUDIOMETER (pl. ii. fig. 29), of which various modifications have been proposed. The general rule for this process is the following: To 100 measures of air, add from 45 to 50 of pure hydrogen gas; inflame the mixture over water by an electric spark; and observe, in a minute or two, the contraction of volume. Dividing this by 3, we have the proportion of oxygen. To insure great accuracy, a number of circumstances are to be observed, which have been stated by Gay Lussac and Humboldt in an elaborate memoir, published in the Journal de Physique, vol. lx.

Though I have made numerous experiments on the analysis of atmospherical air, both by this and other eudiometrical processes, I have not yet been able fully to satisfy myself whether it contains 21 or 20 volumes of oxygen in 100, the proportion having been mostly between those two extremes. Dr. Thomson, in his First Princ. of Chem. i. 96, states that by carefully firing 100 measures of air with 42 of hydrogen, he constantly obtains a diminution of 60 volumes, which ÷ 3 denotes 20 of oxygen. But it may be objected to this result, that the proportion of hydrogen which he employed, even supposing it to be quite pure, would be barely equivalent to saturate 21 volumes of oxygen; and that, under these circumstances, 1 volume, or part of a volume, of oxygen, may very probably have escaped condensation.

Atmospherical air, when very considerably rarefied, is rendered unfit for supporting combustion.—The general fact, that flame ceases in air highly rarefied by the air-pump, was well known to the earlier experimenters upon the Boylean vacuum; but the degree of rarefaction necessary to this effect, has been differently stated. Sir H. Davy (on Flame, p. 57) found that a jet of inflamed hydrogen from what has been called the philosophical candle, of about one-sixth of an inch in height, when introduced under a receiver, containing from 200 to 300 cubic inches of air, enlarged as the receiver was exhausted by an air-pump. When the gauge indicated a pressure between four and five times less than that of the atmosphere, the flame was at its maximum size; it then gradually diminished below, but burned above, till the pressure was between seven and eight times less. Using a larger jet with the same apparatus, it burned till the pressure was reduced to one-tenth that of the atmosphere; and when a coil of platinum wire was kept in the flame in a state of ignition, the combustion did not cease till the pressure was reduced thirteen times. The combustibility of hydrogen in atmospheric air does not, therefore, appear to be increased or diminished by mere rarefaction from the removal of pressure, but to cease in rarefied atmospheres, only when the heat produced is insufficient to keep up the combustion, or at that point when it is incapable of communicating visible ignition to metal. The same law extends to all other combustibles, a circumstance of great importance in the constitution of our atmosphere, which, at the greatest heights or depths at which man can exist, still preserves the same relations to combustible bodies.

It is not, however, by the same degree of rarefaction of air, that the combustion of all bodies is suspended; for, as might naturally be expected, those which require least heat for their combustion, burn in more rarefied air than those that require a higher temperature; and again, those that produce much heat in their combustion, burn in more rarefied air than those which evolve little heat. The following Table, collected from Sir H. Davy's experiments, shows the degrees of rarefaction of common air, at which the combustion of some inflammable bodies ceases, both with and without the appendage of a coil of platinum wire.

	Without Platinum.	With Platinum.
Olefiant gas ceases to burn in air rarefied	- -	11 to 12 times.
Carbureted hydrogen		4 - - -
Carbonic oxide		6 - - -
Alcohol	5 to 6	7 to 8 -
Wax taper		-
Sulphureted hydrogen	7	- - - -
Sulphur	15 to 20	- - - -
Phosphorus	60 - -	- - - -

By preserving heat in rarefied air, Sir H. Davy found that the inflammation of bodies may be continued when, under other circumstances, it would have been extinguished. Thus, when camphor was burned in a glass tube, so as to make the upper part of the tube red-hot, the inflammation continued when the rarefaction was nine times; whereas it would only continue in air rarefied six times, when the camphor was burned in a thick metallic tube, which could not be considerably heated by it. By other experiments he has shown, also, that expansion by heat, instead of diminishing the combustibility of gases, enables them, on the contrary, to explode at a lower temperature.

The power of atmospheric air to support combustion is diminished also by mixing it with some other gases.—Thus, Sir H. Davy found that a candle is instantly extinguished in air mixed with one-tenth of silicated fluoric acid gas, or with one-sixth of muriatic acid gas. But air, thus rendered inadequate to support the combustion of one sort of inflammable substance, is capable of maintaining that of others, as is proved in an elegant manner by the following experiment of the same philosopher. Into a long bottle with a narrow neck introduce a lighted taper, and let it burn till it is extinguished. Carefully stop the bottle, and introduce another lighted taper; it will be extinguished before it reaches the bottom of the neck; then introduce a small tube containing zinc and diluted sulphuric acid, at the mouth of which the hydrogen is inflamed; the hydrogen will be found to burn in whatever part of the vessel it is placed. After the hydrogen is extinguished, introduce lighted sulphur; this will burn for some time; and, after its extinction, phosphorus will be as luminous as in the open air, and, if heated in the bottle, will produce a pale yellow flame of considerable density. (Davy on Flame, p. 82.)

Steam and other vapours, which require a considerable heat for their formation, have a less power of preventing combustion, particularly of those bodies requiring low temperatures, than gases at the common heat of the atmosphere. Thus Sir H. Davy found that a very large quantity of steam was necessary to prevent sulphur from burning. Oxygen and hydrogen exploded by the electric spark, when mixed with five times their volume of steam; and even a mixture of air and carbureted hydrogen, the least explosive of all mixtures, required a third of steam to prevent its explosion, whereas one-fifth of azote produced that effect. (On Flame, p. 86.)

The mechanical condensation of air does not adapt it for supporting a more vivid combustion.—Sir H. Davy's experiments are the only ones we possess on this subject. He condensed air nearly five times, and then ignited iron wire to whiteness in it, by the Voltaic apparatus, but the combustion took place with very little more brightness than in the common atmosphere, and would not continue as in oxygen; nor did charcoal burn much more brightly in this compressed air than in common air. From the experiments of Despretz, (37 Ann. de Ch. et de Ph. 182,) it does not appear that the quantity of heat, given out by charcoal during combustion, is greater or less in condensed oxygen gas than in gas of common density; and he is of opinion that the same uniformity would be observed in the combustion of sulphur and of other bodies, which burn in oxygen without changing its volume.

Atmospheric air supports animal life only in consequence of the oxygen gas which it contains.—Air, after having been received into the lungs, and again expired, is found to have lost a considerable part of its oxygen, *viz.* from 10 to 12 per cent. It proves fatal to animals, however, long before this element is wholly exhausted; and hence it appears that a considerable proportion of oxygen gas is necessary to fit the air for supporting respiration. As the analysis of expired air requires an acquaintance with another gas, not hitherto described, *viz.* carbonic acid, its examination will be postponed to a future occasion.

Atmospheric air is diminished in volume by animal respiration.—

This may be shown by repeating a very simple experiment, originally contrived by Mayow. He confined a mouse in a small glass jar, and tied the jar over, quickly and firmly, with moistened bladder. The heat of the animal first expanded the air, and rendered the bladder convex outwards; but when the animal, after death, had become cold, the bladder exhibited a hollow surface, proving that the air within the jar was diminished in bulk.

The exact amount of the diminution may be shown, by confining a mouse, over water, in a graduated jar, furnished with a stopcock, and containing common air. As the heat of the animal, however, would occasion the expulsion of part of the air, it is expedient, on first depressing the jar into water, to open the cock, through which a part of the air will escape; the cock is then to be shut, and the height of the water within to be accurately noted. At first the level will be depressed, in consequence of the expansion of the air by the warmth of the animal; but, after its death, a sensible diminution will have taken place.

Weight of air.—The weight of 100 cubic inches of atmospheric air, at 60° Fahr. and 30 inches barometer, is said by Mr. Kirwan to be 30.92 grains. Sir H. Davy states it, when under the same pressure, but at 55° Fahrenheit, to be 31.10 grains; from which it may be deduced that, with the temperature and pressure assumed by Mr. Kirwan, 100 inches would weigh 30.78 grains. Under the same circumstances, Sir George Shuckburgh's experiments fix its weight at 30.5 grains, a number confirmed by the subsequent investigations of Mr. Rice. (Ann. of Phil. vol. xiii.) Mr. Brande, (Manual, i. 379,) deduces, from twelve experiments made at the Royal Institution, with great care and an excellent balance, that 100 cubic inches of air, at a mean of the barometer and thermometer, weigh only 30.199 grains. This Dr. Prout considers as below the truth. (Phil. Trans. 1827; and Turner's Chemistry, 2d. edit. p. 808.) And his experiments, and those of Mr. Dalton, (New System, ii. 301.) with which my own agree, make its weight fully 31 grains, after the necessary corrections for moisture. On the whole, perhaps, 31 grains may be considered as a near approximation to the correct weight of 100 cubic inches of atmospheric air at a mean of the barometer and thermometer, and either dry or corrected for aqueous vapour.

Constitution of the atmosphere.—All eudiometrical processes have hitherto concurred to prove that, apart from the carbonic acid and aqueous vapour, and, according to the experiments of Vogel and others, a little muriatic acid (Ann. of Phil. N. S. vi. 25), which are present in atmospheric air, 100 volumes consist of nearly 21 oxygen, and 79 nitrogen; or, including the two former ingredients, that it is constituted, at a mean temperature and pressure, of

Nitrogen gas - - -	77.5	by measure - -	75.55	by weight.
Oxygen gas - - -	21.	- - - - - - -	23.32	
Aqueous vapour - -	1.42	- - - - - - -	1.03	
Carbonic acid - -	0.08	- - - - - - -	0.10	
	100.00		100.00	

It is remarkable, that, with the exception of the aqueous vapour, the quantity of which varies with the temperature, as will presently appear; of a little muriatic acid, which is only found in air within a certain distance from the sea; and, according to Liebig, of a trace of nitric acid, discoverable in rain which has fallen immediately after lightning (An. de Ch. &c. July 1827); the other ingredients of the atmosphere bear at all times, in all quarters of the globe, and at all accessible heights above its surface, the same relative proportion to each other. Thus air from the Alps analyzed by Saussure, jun., from Spain by De Marti, from France and Egypt by Berthollet, from England and the coast of Guinea by Davy, from the Peak of Teneriffe and from near the summit of the Andes by Humboldt, and from the height of nearly 22,000 feet by Gay Lussac and Thenard, all gave results approaching as nearly as possible to each other. The unknown ingredients which are occasionally mingled with the atmosphere, and which impart to it deleterious properties, are either of too subtile a nature, or present in too small a proportion to be discoverable by our imperfect instruments.

Two views have been taken of the nature of the union, which exists among the several elastic fluids constituting the atmosphere. By the greater part of chemists it has been considered as a chemical compound, chiefly from the uniformity of its composition, and from the fact that its several ingredients do not separate and arrange themselves according to their respective specific gravities. Mr. Dalton was the first who presented, under a distinct view, the theory, that of the various elastic fluids constituting the atmosphere, the particles of one have neither attractive nor repulsive power towards those of another; but that the weight or pressure, upon any one particle of any fluid mixture of this sort, arises solely from the particles of its own kind. (Manchester Memoirs, v. 583.) According to this hypothesis, oxygen, azotic, and carbonic acid gases (or indeed any number), may exist together under any pressure, and at any temperature, while each of them, however paradoxical it may at first appear, occupies the whole space allotted for all. Each ingredient of the atmosphere, on this view, exerts its own separate pressure in supporting the mercury of the barometer, and performs the part assigned to it in the following Table:

		Inch. of Mercury.
The Nitrogen gas exerts a pressure - - -	=	23.36
Oxygen gas - - - - - - - - - -	=	6.18
Aqueous vapour - - - - - - - - -	=	0.44
Carbonic acid gas - - - - - - - - -	=	0.02
		30.00

To enter fully into the arguments for and against this doctrine, would lead into discussions of too great length for an elementary work. The subject, too, has already been brought before the reader in a preceding chapter, in speaking of the nature of the connexion which exists between aqueous vapour and permanently elastic fluids. (See p. 130.) I shall only, therefore, express my opinion, that on the whole the new view is more probable, and encumbered with fewer difficulties, than the theory*that the constituents of the atmosphere are held united by chemical affinity. A strong argument in its favour is derived from the recent experiments of Dulong, which show that the refractive power of atmospheric air is precisely equal to the sum of the refractive powers of its elements. (Ann. de Ch. et de Ph. xxxi. 165.) Mr. Dalton has candidly acknowledged, (Man. Mem. 2d Series, i. 257,) that, taking the azotic part of the atmosphere as a standard, the oxygen and carbonic acid must, if his theory be true, observe a decreasing ratio in ascending, and the aqueous vapour an increasing one. But on the summit of Mont Blanc (nearly three English miles in perpendicular height) the ratio of the oxygen to the nitrogen, supposing it to be as 21 to 79 under mean pressure, would still be very nearly as 20 to 80, and at all ordinary heights the difference of proportion must be scarcely appreciable. On this subject, the reader may consult a paper published by Mr. Dalton in the Philosophical Transactions for 1826, in which the views of that philosopher, respecting the constitution of the atmosphere at different elevations, are fully developed.

General View of the Compounds of Nitrogen and Oxygen.

When nitrogen and oxygen gases are mingled together, in whatsoever proportions they are employed, no combination ensues. The result is a simple mixture of the two gases, which do not, like inelastic fluids, separate on standing, but remain diffused through each other for an indefinite length of time. When, however, either one or both of these elements is in a condensed state, or deprived of part of that caloric which keeps the gravitating particles of gases at a distance from each other, they unite and form compounds, distinguished by very striking properties. According to the proportions in which the oxygen and nitrogen exist in these compounds, their qualities undergo a remarkable variation, so that, from two elementary bodies, variously united, we have several compounds, totally unlike each other in external qualities, as well as in their chemical relations.

Before describing the compounds of oxygen and nitrogen individually, it will contribute to perspicuity to take a general survey of the whole. Some of them exist essentially in an aëriform state, and are capable of uniting with water and other liquids in small proportion only. Others, again, combine with water to such an extent, that the liquid form is the only one under which they occur to our observation. When entirely deprived of water, they are all essentially gaseous bodies.

In a series of the compounds of nitrogen, founded on their proportion of oxygen, they occupy (excluding atmospherical air from the number), the following order, the last containing the largest proportion of oxygen, *viz.* nitrous oxide, nitric oxide or nitrous gas, hypo-nitrous acid, nitrous acid or nitrous vapour, and nitric acid. The two first are sparingly soluble in water; but the three last unite with it largely, and form liquid compounds of decidedly acid taste and qualities.

The following table exhibits the composition, by weight, of three of these bodies, the calculation being founded on the experiments of Sir H. Davy, published in the year 1800 in his "Researches."

Table 1.

	Nitrog.	Oxyg.		Nitrog.	Oxyg.
Nitrous oxide (protoxide) -	63.30	36.70		14	8.117
——— gas (deutoxide) - -	44.05	55.95	or	14	17.690
Nitrous acid* - - - - - -	29.50	70.50		14	33.460

When these weights are converted into volumes, (taking 100 cub. in. of oxygen gas at 33.8 grains, and 100 in. of nitrogen at 29.5 gr.) we obtain the following proportions.

Table 2.

	Vols. of	
	Nitrog.	Oxyg.
1. Nitrous oxide (protoxide) - - - -	100	50.63
2. ——— gas (deutoxide) - - - - -	100	110.00
3. ——— acid - - - - - - - - - -	100	208.60

The experiments of Sir H. Davy, though made at a time when the instruments and processes of gaseous analysis were much less perfect than at present, are of great value, because the observation of their results could not have been influenced by any hypothesis respecting volumes or atoms. It appears, from the second table, that the proportions, as to volumes, of the elements of nitrous oxide, are almost precisely those now admitted to constitute that gas. In the second and third compounds, the deviation from recent experience is not greater than might be expected. The table shows, also, that, in the second compound, the oxygen is not far from a multiple by 2 of that in the first; and that the oxygen in the third is little less than a multiple by 2 of that in the second. These coincidences, and others of the same kind, suggested to Gay Lussac the theory *that compounds, whose elements are gaseous, are constituted either of equal volumes of those elements; or, that if one of the elements exceeds the other, the excess is by some simple multiple of its volume.* That the proportions of nitrogen and oxygen by measure do not, in the foregoing instances, rigorously conform to this law, is with great probability ascribed by Gay Lussac to unavoidable inaccuracies, attendant on all delicate processes for determining the specific gravity and constitution of gaseous bodies. In one instance, the coincidence was proved experimentally by Berard, who, by the combustion of potassium in 100 measures of nitrous gas, obtained exactly 50 measures of nitrogen; and this has since been proved to be the true proportion of its elements. Hence the table, corrected

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[*] These were at first stated to be the proportions of the elements of *nitric* acid; but they apply correctly to *nitrous* acid.

to accord with the views of Gay Lussac, and enlarged so as to comprehend all the known compounds of nitrogen, will stand as follows:

Table 3.

	Proportions by volume.		Proportions by weight.	
	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.
Nitrous oxide consists of	100	50	14	8
——— gas	100	100	14	16
Hypo-nitrous acid	100	150	14	24
Nitrous acid	100	200	14	32
Nitric acid	100	250	14	40

In all the above compounds, the elements are in a state of condensation, except in nitrous gas, in which the nitrogen and oxygen are precisely in the same state of density, as in nitrogen and oxygen gases. In the other compounds, the contraction is exactly equivalent to the volume of the oxygen gas; or, in other words, the volume of the compound is equivalent to that of the nitrogen. For example,

In 1 vol. of nitrous oxide, the contraction is 0.5 vol.
- - - - nitrous gas - - - - - - 0.0
- - - - hypo-nitrous acid - - - - 1.5
- - - - nitrous acid gas - - - - - 2.0
- - - - nitric acid gas - - - - - 2.5

Taking, then, the specific gravity of oxygen gas at 1.1111, and that of nitrogen at 0.9722, and knowing the proportions of those elements, and their condensation, it is easy to calculate what ought to be the true specific gravity of the compound gases. In some cases, especially in those of the acid compounds of nitrogen, their density is best arrived at by this method, which should always be used as a check upon actual weighing. The density of nitrous gas, the elements of which undergo no contraction, is represented by half the sum of the densities of oxygen and nitrogen gases. Nitrous oxide has a sp. gr. equal to the density of nitrogen + half that of oxygen; and hypo-nitrous, nitrous, and nitric acid gases the density of nitrogen + 1.5, 2, and 2.5 times the density of oxygen respectively.

Mr. Dalton, who was the first to observe the law of simple multiples in the compounds of oxygen with nitrous gas, has given, in his "New System of Chemical Philosophy," a table of the compounds of nitrogen and oxygen, which differs essentially from that of Gay Lussac. This table, however, it is unnecessary to copy, because it has been since materially altered by the author, who has presented the combining volumes under the following corrected form. (Thomson's Annals, ix. 193.) The proportional weights I have estimated from data already given (p. 268).

Table 4.

	Volumes of			By weight.		
	Nitrogen.		Oxygen.	Nitrogen.		Oxygen.
Nitrous oxide - -	100	+	62 - - -	14	+	10
——— gas - -	100	+	124 - - -	14	+	20
Hypo-nitrous acid	100	+	186 - - -	14	+	30
Nitrous acid - -	100	+	248 - - -	14	+	40
Nitric acid - -	100	+	310 - - -	14	+	50

It will be obvious, from a comparison of this table with Table 3, that it assigns to all the compounds of nitrogen considerably more oxygen than is admitted by Gay Lussac and others to enter into their composition. It is allowed, on all hands, that, setting out from nitrous oxide, the other compounds of nitrogen contain proportions of oxygen, which are simple multiples, both in weight and in volume, of the oxygen existing in nitrous oxide. The only question, then, that can remain, is, whether it be true that one volume of nitrogen unites with exactly half a volume of oxygen, to constitute nitrous oxide. Now of this fact I have fully satisfied myself, by a set of analytical experiments, made with every precaution that could be thought of to insure accuracy; with no undue influence from theoretical views; and in the presence of several competent witnesses, before whom they have been frequently repeated. In the course of the same series of experiments, I obtained the fullest evidence that, in nitrous gas, the elements are in equal volumes, and that, in nitric acid, the volumes are 1 of nitrogen to 2.5 of oxygen. The third table may, therefore, be considered as giving a correct view, both as to weights and volumes, of the elements of the five known compounds of nitrogen and oxygen.

With respect, however, to the determination of the atomic weights of nitrogen and oxygen, and to the decision of the point, which of their compounds we are to take as the true binary one of an atom of each element, there is still room for discussion. Dalton and Berzelius consider nitrous gas (deutoxide) as the true binary compound, and regard nitrous oxide as 2 atoms of nitrogen + 1 atom of oxygen; while the greater number of chemists set out from nitrous oxide as the compound of 1 atom of each element, and consider nitrous gas as 1 atom of nitrogen + 2 atoms of oxygen. Nor is this a difficulty which can be cleared up by experiment, since it arises entirely out of the manner in which we choose to interpret the facts. The case is precisely analogous to the one which I have already stated with regard to the atomic weight of copper and its oxides. (P. 56.) It is obvious that, in this instance, the proportion of 14 nitrogen to 16 oxygen, constituting nitrous gas, is the same as that of 7 to 8. Having, then, from an extensive survey of the compounds of oxygen with other bodies, arrived at 8 as the number expressing its atomic weight, we are quite at liberty to take 7 as the representative number of nitrogen. We should then have $7 \times 2 = 14 = 2$ atoms of nitrogen in nitrous oxide. Nor, so far as the evidence of direct experiment goes, is the one view more probable than the other; and the question can only be investigated by examining probabilities, derived from other considerations. The two views are contrasted in the following Table:—

	Nitr. 7.	Ox. 8.	At. Wt.	Nit. 14.	Ox. 8.	At.Wt.
Nitrous oxide -	2 at. +	1 at. =	22	1 at. +	1 at. =	22
——— gas - -	1 at. +	1 at. =	15	1 at. +	2 at. =	30
Hypo-nitric acid	2 at. +	3 at. =	38	1 at. +	3 at. =	38
Nitrous acid -	1 at. +	2 at. =	23	1 at. +	4 at. =	46
Nitric acid -	2 at. +	5 at. =	54	1 at. +	5 at. =	54

To state, otherwise than very briefly, the arguments in favour of each of the above views, would lead me into discussions unsuitable to the nature of this work. In behalf of the opinion that, nitrogen being 14, the oxygen, in its compounds, is in the arithmetical proportion of 8, 16, 24, 32, 40, may be advanced the greater simplicity of that view, and its accordance with the results of analysis. In favour of the second, Mr. Dalton has argued that, since nitrous gas is more difficultly decomposed by combustible bodies than nitrous oxide, we may, agreeably to the method of reasoning of which I have given an example at pp. 56, 57, consider the former as the more simple compound. He alleges, also, that when we electrify mixtures of nitrogen and oxygen gases, we generally find that nitrous gas is produced, but never nitrous oxide; and that it is most reasonable to suppose that, under such circumstances, the binary compound will be most easily formed.

The adoption of the opinion that 7 is the atomic weight of nitrogen would materially alter our views of ammonia. In that compound, it is ascertained that we have by weight 14 nitrogen + 3 hydrogen, or 1 atom nitrogen + 3 atoms of hydrogen. But, if 7 represent the atom of nitrogen (the atom of hydrogen being already determined to be 1 from the composition of water) we shall have in ammonia 1 atom of nitrogen + 1.5 hydrogen; or, to overcome the difficulty of half an atom, 2 atoms of nitrogen + 3 atoms of hydrogen. This manner of viewing the phenomena would lead to such an extensive change in the equivalent numbers now generally received, that, till stronger reasons can be given for halving the atomic number for nitrogen, I shall continue to represent nitrogen by 14, and the oxygen, in its compounds, as multiples of 8 by 1, 2, 3, 4, and 5.

Protoxide of Nitrogen.—Nitrous Oxide of Davy.

This compound of oxygen and nitrogen may be obtained by several processes:

(1) By exposing common nitrous gas for a few days to iron filings, or to various other bodies strongly attracting oxygen, the former gas is changed into nitrous oxide. Some nicety and experience are required to suspend the decomposition before it has gone too far; in which case nitrogen gas is obtained along with nitrous oxide. The sulphite of potassa, being incapable of decomposing nitrous oxide, is better adapted to the conversion of nitrous gas into that elastic fluid. The process, in all cases, may be sus-

pended, when about two-thirds of the original bulk of the gas are left.

(2) By dissolving zinc, or tin, in nitric acid, diluted with five or six times its weight of water. Zinc, during this solution, disengages nitrous oxide till the acid begins to exhibit a brownish colour, when the process must be suspended, as nitrous gas is then formed. But by neither of these methods is the gas obtained sufficiently pure for exhibiting its qualities. For procuring it in a state of purity, the following is the best process.

(3) To nitric acid, diluted with five or six parts of water, add the common carbonate of ammonia of the shops, till the acid is saturated. Then evaporate the solution by a gentle heat, until a glass rod, when dipped into it, and rapidly cooled, is found to have acquired a solid coating; and, to supply the waste of alkali, add, occasionally, a little more of the carbonate. The salt, obtained after the solution has cooled, is next to be put into a glass retort, and distilled with a sand-heat not exceeding 440° Fahr.* The heat of an Argand's lamp is more than sufficient, and requires cautious regulation. The salt will presently liquefy, and must be kept gently simmering, avoiding violent ebullition. The gas may be collected over water, and allowed to stand a few hours before it is used, during which time it will deposit a white substance, and will become perfectly transparent. A gazometer, however, is best adapted for its reception, because all danger is then avoided of the water of the trough being forced into the retort; and because the gas is brought into contact with a much smaller surface of water, which has the property of absorbing a considerable proportion of the gas. On this account, water, which has been once used to confine the gas, may be kept for the same purpose.

The changes that take place, during the conversion of nitrate of ammonia into nitrous oxide, are shown by the following diagram:

$$\text{Nitric Acid 54.}\left\{\begin{array}{ll}\overset{\text{28 Nitrous oxide.}}{\overline{\text{Oxygen 40.}\quad\text{Hydrogen 3.}}}\\ \underset{\text{27 Water.}}{\underline{\text{Nitrogen 14.}\quad\text{Nitrogen 14.}}}\end{array}\right\}\text{Ammonia 17.}$$

Nitrate of ammonia consists (exclusively of water) of 54 nitric acid and 17 ammonia. Now 54 parts of nitric acid are composed of 40 oxygen and 14 nitrogen; and 17 of ammonia consist of 3 hydrogen and 14 nitrogen. At a high temperature, the balance of affinities, which preserved the original compound, is disturbed; the 3 parts (or atoms) of hydrogen unite with 3 atoms of oxygen (8 × 3 = 24) to form 27 of water; and the residuary 16 of oxygen (= 2 atoms) combine with the whole nitrogen 28 (also equal to 2 atoms), or, dividing both numbers by 2, we have 8 oxygen (= 1 atom) combined in the resulting gas with 14 (= 1 atom) of nitrogen.

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* From the observations of Mr. Sadler (Nicholson's Journal, xv. 286), it appears that the purity of the nitrate of ammonia is of considerable importance; and that its adulteration with muriate diminishes the quantity, and impairs the quality of the gas, obtained from it by heat.

The gas, thus obtained, was termed, by its discoverer, Dr. Priestley, *dephlogisticated nitrous air;* by the associated Dutch chemists, *gaseous oxide of azote.* Its most appropriate title is *protoxide of nitrogen;* but, for the sake of brevity, I shall occasionally use, with Sir H. Davy, the name of nitrous oxide. An elaborate investigation of its properties and composition has been described by that philosopher, in his "Researches, Chemical and Philosophical." London, Johnson, 1809.

In order to ascertain whether nitrous oxide be adulterated with either common air or oxygen gas, we may mix equal measures of the gas under examination, and of nitrous gas. If any diminution ensue, the presence of one of these may be suspected; and the amount of the diminution will show which of them is contained in it. Nitrous gas, however, is a much more common contamination; for it is generated, along with nitrous oxide, whenever the temperature of the salt is raised too high. Its presence may be detected either by red fumes and a diminution on the admixture of oxygen gas, or by an absorption being effected on agitating the gas with a solution of green sulphate of iron, which has no action on pure nitrous oxide.

Nitrous oxide gas has the following properties:

Specific gravity.—It is considerably heavier than common air. At about 55° Fahr. and 30 inches pressure, 100 cubic inches weigh 50.20 grains, or under the same pressure, and at 60° Fahr. 49.68. (Davy.) More recently Sir H. Davy has stated 100 cubic inches to weigh between 48 and 49 grains, and hence its specific gravity should be very nearly 1.6. Colin makes it only 1.5204, or, corrected by calculation, 1.5209; Dr. Thomson 1.5269, or 1.5277 by calculation; and Berzelius and Dulong 1.5273. These slight differences in the results of calculation arise from trifling disagreements as to the specific gravities of its elements; for, as the compound gas consists of ½ vol. of oxygen and 1 vol. of nitrogen, in the space of 1 vol., we obtain its specific gravity by adding half the sp. gr. of oxygen gas to the sp. gr. of nitrogen gas.

Liquefaction.—Nitrous oxide was produced by Mr. Faraday under great pressure, in a liquid form. Some nitrate of ammonia, made as dry as possible, was sealed up in a bent tube, which was heated at one end, the other end being kept cool. Two fluids were thus obtained; the heavier, on examination, proved to be water, with a little acid and nitrous oxide in solution; the other was nitrous oxide in a liquid state. It was colourless, limpid, and so volatile, that the warmth of the hand caused it to disappear in vapour. It boiled readily by the difference of temperature between 0 and 50°. It had no tendency to solidify at — 10° Fahr. A tube being opened in the air, the nitrous oxide instantly burst into vapour, and another tube being opened under water, the gas was collected. A gauge being introduced into a tube, in which liquid nitrous oxide was afterwards produced, gave the pressure of its vapour equal to above 50 atmospheres at 45° Fahr. (Phil. Trans. 1823, p. 195.)

Action of water.—Nitrous oxide is rapidly absorbed by water that has been previously boiled, about one-thirtieth the original bulk of the gas remaining uncondensed. A quantity of gas, equal to considerably more than nine-tenths the bulk of the water, may be thus made to disappear. This property furnishes a test of the purity of nitrous oxide; for the pure gas is almost entirely absorbed by boiled water, which has cooled without the access of air. The gas employed should exceed the water three or four times in bulk, in order to obtain a saturated solution; but, whatever care be used, the proportion of the unabsorbed residuum will be liable to some variation, from the uncertain quantity of other gases extricated from the water itself.

Water, that has been saturated with this gas, gives it out again, unchanged, when heated. The impregnated water does not change blue vegetable colours. It has a distinctly sweet taste, and a faint, but agreeable, odour.

Electrification.—Sir H. Davy, by passing electric sparks for some time through seven measures of nitrous oxide over mercury, found it reduced to 6½ measures. The residue was a gas analogous in properties to atmospheric air; and some nitrous acid was also produced. (Researches, p. 282.)

Action of heat.—When passed through a porcelain tube, well glazed both inside and outside, and strongly ignited in a furnace, a gas came over which was rendered opaque by dense red vapour; but which, after the spontaneous condensation of this, exhibited very nearly the same properties as atmospheric air. Neither this mode of decomposition, however, nor the last, furnishes results sufficiently exact to give any insight into the proportion of the components of nitrous oxide.

Action of combustibles.—A candle burns in nitrous oxide with a brilliant white flame and crackling noise. Before its extinction, the white inner flame becomes surrounded with an exterior blue one.

Phosphorus, introduced into it in a state of inflammation, burns with increased splendour. Phosphorus, however, may be melted and sublimed in this gas without alteration. It may even be touched with red-hot iron wire, without being inflamed; but when wire intensely heated, or made white-hot, is applied, the phosphorus burns, or rather detonates, with prodigious violence.

Sulphur, introduced into nitrous oxide when burning with a feeble blue flame, is instantly extinguished; but when in a state of active inflammation, it burns with a vivid and beautiful rose-coloured flame.

Red-hot charcoal burns in nitrous oxide more brilliantly than in the atmosphere. When the experiment is made in a proper apparatus, the results of its combustion are found to be one measure of nitrogen gas and half a measure of carbonic acid (equivalent to half a measure of oxygen) from each measure of nitrous oxide.

A mixture of this gas with hydrogen gas detonates loudly, on applying a lighted taper, or passing an electric spark, and is decomposed also by spongy platinum at common temperatures.

When the proportion of hydrogen a little exceeds in volume that of nitrous oxide, *viz.* as 40 to 39, nitrogen gas only, = 41 measures, remains after the explosion; but when the proportion of hydrogen is smaller, nitric acid is also generated. In general terms, it may be stated that 2 volumes of nitrous oxide require for decomposition 2 volumes of hydrogen gas, and leave after combustion 2 volumes of nitrogen. Now we know that 2 volumes of hydrogen are equivalent to the saturation of 1 vol. of oxygen, which, with the 2 remaining volumes of nitrogen, must make up the composition of 2 volumes of nitrous oxide. In other words, 1 vol. of nitrous oxide consists of 1 vol. of nitrogen + $\frac{1}{2}$ vol. of oxygen condensed into the space of 1 vol. And as 1 vol. of nitrogen, and $\frac{1}{2}$ vol. of oxygen gases, are each equivalent to an atom, nitrous oxide must consist of 1 atom of nitrogen weighing 14, and 1 atom of oxygen = 8; its representative number will therefore be 22.

Nitrous oxide forms (as I have shown, Philosophical Transactions, 1809, p. 444,) a combustible mixture with ammoniacal gas, 100 measures of the latter requiring for perfect decomposition 150 measures of nitrous oxide. It burns also, as Davy has shown (Researches, p. 373), when mixed with olefiant gas; and I have pointed out an easy and summary way of analyzing it, by firing it over mercury with carbonic oxide. (Ann. of Phil. N. S. viii. 229.) In this case, 1 vol. of nitrous oxide is decomposed by 1 vol. of carbonic oxide, and there result 1 vol. of carbonic acid and 1 vol. of nitrogen. On this property is founded a ready and correct method of testing the purity of nitrous oxide. Let a given volume be exploded with a slight excess of carbonic oxide of known purity; for example, 110 or 115 measures of the latter to 100 of nitrous oxide. If the nitrous oxide be pure, we ought to obtain 100 measures of carbonic acid gas, and whatever is short of that proportion we may impute to the presence of foreign gas in the nitrous oxide. It is of course implied that the gas has been found, by the test of solution of green sulphate of iron, to be free from nitrous gas or nitric oxide.

Iron wire burns in this gas with much the same appearance as in oxygen gas, but for a shorter period.

Action of oxygen gas, &c.—Nitrous oxide is not diminished by admixture with either oxygen or nitrous gas, nor is it altered by contact either with chlorine or iodine.

Action of alkalies.—Nitrous oxide is not absorbed by alkalies; but if it be brought into contact with them, when in a nascent state, or before it has assumed the form of a gas, it then enters into combination with alkaline bases. Thus, when a mixture of sulphite of potassa and pure potassa is exposed to nitrous gas, the gas is deoxidized by the sulphite, and changed into nitrous oxide, which unites with the alkali. We obtain, therefore, a mixture of sulphate of potassa with a compound of nitrous oxide and alkali, the former of which may be separated by priority of crystallization. The latter is composed of about three parts of alkali, and one of nitrous oxide. It is soluble in water; has a caustic taste, of peculiar pungency; and converts vegetable blues to green. Powdered charcoal, mingled with it, and inflamed, burns with bright scintillations. The nitrous oxide is expelled from fixed alkalies by all acids, even by the carbonic.

Respiration.—Animals, when wholly confined in this gas, die speedily.

One of the most extraordinary properties of this gas, is exhibited by its action on the human body, when received into the lungs. When thus employed, it does not prove fatal, because, when admitted into the lungs, it is mixed and diluted with the atmospherical air present in that organ. To administer the gas, it may be introduced into an oiled silk bag or clean bladder, furnished with a stop-cock, and may be breathed repeatedly from the bag and back again, as long as it will last. The sensations that are produced vary greatly in persons of different constitutions; but, in general, they are highly pleasurable, and resemble those attendant on the early period of intoxication. Great exhilaration, an irresistible propensity to laughter, a rapid flow of vivid ideas, and an unusual fitness for muscular exertion, are the ordinary feelings it produces. These pleasant sensations, it must be added, are not succeeded, like those accompanying the grosser elevation from fermented liquors, by any subsequent depression of nervous energy.

Deutoxide of Nitrogen.—Nitrous Gas, or Nitric Oxide.

This gas, though discovered by Dr. Hales, was first distinctly examined by Dr. Priestley, and called by him *nitrous air*, a term afterwards changed to *nitrous gas*, then to *nitric oxide*, and more lately to *deutoxide of azote*, or *deutoxide of nitrogen*, which last appears to be its appropriate title. It is so generally known, however, under the name of nitrous gas, that I shall sometimes, for the sake of brevity, continue so to call it.

Nitrous gas may be easily obtained by pouring, upon filings or turnings of copper contained in a gas bottle, nitric acid of density 1.2 or 1.3, without applying any other heat than that occasioned by the action of the acid and metal on each other. Quicksilver may be substituted for copper, and with either metal a more dilute acid may be employed, but in the latter case it will be found necessary to apply heat to the materials. During this process, part of the nitric acid gives oxygen to the copper, and passes to the state of nitrous gas; and the remaining acid unites with the deutoxide of copper, and composes the deuto-nitrate of that metal.

The properties of nitrous gas are the following:—

Action of water.—It is permanent over water; but it is absorbed in the proportion of about 1 volume to 18 or 20, when agitated with water which has been recently boiled, and has become cold. This solution, according to La Grange, is converted, by long keeping, into nitrate of ammonia, in consequence of the decomposition of the water.

Nitrous gas is rather heavier than common air. One hundred cubic inches at 55°, barometer 30°, were stated by Sir H. Davy in 1800, to weigh 34.26, or at 60° Fahr. 33.80 grains. He has since, however, given the weight of 100 cubic inches at 32 grains, and hence its specific gravity at 1.050. Berard's determination is considerably lower; *viz.* 1.0388 by experiment, or 1.0364 corrected by calculation; Dr. Thomson's 1.0409 by experiment, or 1.0416 from the proportion of its elements; for 1.1111 + 0.9722 = 2.0833, which, divided by 2, gives 1.0416.

When well washed with water, it is not acid. It will be found not to redden the colour of litmus. This may be shown by introducing a piece paper, tinged with that substance, into a jar of nitrous gas, standing inverted over water. To accomplish this, the paper should be fastened to the end of a glass rod or a piece of stick. The colour will remain unchanged.

Action of Combustibles.—It extinguishes a lighted candle, the flame of which is, however, enlarged before going out. Homberg's pyrophorus is instantly inflamed by it; and charcoal, or phosphorus, introduced into it when in a state of actual combustion, continue to burn vehemently.

It is fatal to animals, even to the amphibia, and to insects which are capable of respiring for some time other deleterious gases.

Mingled with hydrogen gas, it imparts a green colour to its flame; but it does not explode with hydrogen in any proportion, nor with any of the varieties of carbureted hydrogen except with olefiant gas, the proportion of which requires to be nicely adjusted, *viz.* rather more than seven measures of nitrous to one of olefiant gas. A mixture of hydrogen and nitrous gases is, however, decomposed by spongy platinum at common temperatures. When mixed with ammonia, an electric spark produces a detonation, as I have shown in the Philosophical Transactions for 1809. The proportions, required for mutual saturation, are about 150 measures of pure nitrous gas to 100 of ammonia. Gay Lussac found these gases, also, to act slowly on each other at common temperatures, being reduced in about a month to half their joint volume, and nitrogen being liberated.

Action of oxygen gas.—When nitrous gas is mixed with oxygen gas, red fumes arise; heat is evolved; a diminution takes place; and if the two gases be in proper proportion, and perfectly pure, they disappear entirely. Ten measures of oxygen, Mr. Dalton asserts, may be made to condense any quantity of nitrous gas, between 13 and 36 measures, accordingly as the mixture is conducted; and Gay Lussac finds that 100 measures of oxygen gas condense over water from 134 to 365 of nitrous, but in a dry glass vessel only 204, which, allowing for inaccuracies, may be stated at 200. (Ann. de Ch. et de Phys. i. 399.) In the latter case the total 300 measures become 200 of nitrous acid vapour. The following table shows the proportions, in which nitrogen and oxygen exist in the compounds, resulting from the condensation of 100 measures of oxygen by 365, 200, and 134 measures of nitrous gas respectively, reckoning the oxygen in nitrous gas at one half of its volume, and the nitrogen at the same.

Volumes of		Resulting compound contains	
Nitrous.	Oxygen.	Vols. of Nitrogen.	Vols. of Oxygen.
365	100	100	154
200	100	100	200
134	100	100	250

In the first case the resulting compound contains an excess of only four volumes of oxygen above those assigned to *hypo-nitrous acid;* the second agrees with *nitrous acid;* and the third with *nitric acid. Nitrous* acid may also be generated by passing into a tube, from 8-10ths of an inch to 1 inch diameter, first 200 measures of nitrous gas and then 200 oxygen. The absorption amounts to 300 measures, and 100 of oxygen remain; the resulting compound therefore is constituted of 100 vols. nitrogen and 200 oxygen. If to 100 oxygen we add 400 nitrous gas, the absorption is 400, and 100 of nitrous gas remain. But 100 oxygen + 300 nitrous gas are equivalent to 250 oxygen + 150 nitrogen, and to 100 nitrogen + 166.66 oxygen, proportions which do not agree with those of any definite compound of nitrogen and oxygen. The anomaly, however, as has been well shown by Prof. Dana, (Amer. Journal of Science, vii. 341,) may be satisfactorily explained as follows:

50 vols. of oxyg. unite with 200 nitrous gas, forming hypo-nitrous acid.
50 vols. do. - - 100 do. forming nitrous acid.
100 300

Use of nitrous gas in eudiometry.—On mixing nitrous gas with atmospheric air, the diminution is proportional to the quantity of oxygen gas which the latter contains. On its property of condensing oxygen, but no other gas, is founded the application of nitrous gas to the purpose of *eudiometry*, or of ascertaining the purity of air. The sources of error, in its employment in this mode, have hitherto been considered such, as to forbid our relying implicitly on the results which it may afford. Learning, however, from Mr. Dalton, that he constantly employs nitrous gas in determining the purity of air, and with perfect satisfaction as to the accuracy of his results, I have obtained from him the following communication. It may be necessary to premise, that for applying nitrous gas to this purpose, two tubes will be found convenient, shaped like fig. 24; each from three to four tenths of an inch in diameter; eight or nine inches long, exclusive of the funnel-shaped part; and accurately graduated into minute aliquot parts. What these parts are, is of no consequence. Hundredth parts of a cubical inch give rather too large divisions of the scale; but if each of these be divided into two, the scale will be sufficiently small. If the tube employed be not long enough to comprise 100 of these parts, the experiment may be made on 50 parts only of atmospherical air; and the results, multiplied by 2, will give the proportion in 100 parts.

"To use nitrous gas accurately in eudiometry, it is only requisite to take both gases in a dilute state, namely, containing four or five times their bulk of azotic gas (which atmospheric air naturally does), or of any other gas not acted upon by nitrous or oxygen gases. In this case, if an excess of one gas be used, the other is, in a few minutes, entirely taken up, and in a constant proportion; whatsoever may be the form of the vessel, or the manner of mixing the gases. The proportion is 1 of oxygen to 1.7 of nitrous, so that 10-27ths of the diminution over water are oxygen, and 17-27ths nitrous gas. It is proper, as soon as the greater part of the diminution has ensued, to transfer the mixture through water into a graduated vessel, without using any agitation.

"If pure nitrous gas be admitted to pure oxygen gas in a narrow eudiometer tube, so that the oxygen gas is uppermost, the two unite very nearly in the same uniform proportion as above. If, on the other hand, the nitrous be the upper gas, a much less quantity of it disappears, *viz.* 1.24 nitrous to 1 oxygen. If undiluted nitrous gas be admitted to pure oxygen gas, in a wide vessel over water, the whole effect takes place immediately; and one measure of oxygen will condense 3.4 nitrous gas.

"To render this rule more intelligible, an example may be necessary. Let 100 measures of common air be admitted to 100 measures of a mixture of nitrous gas, with an equal volume of azotic or hydrogen gas. After standing a few minutes in the eudiometer, there will be found 144 measures. The loss 56 being divided by the common divisor, 2.7, gives 21 nearly for the oxygen gas present in 100 measures of common air."

To these directions I may add, that when atmospherical air is the subject of experiment, it is scarcely necessary to dilute the nitrous gas, with any other gas, previously to its use. If a number of experiments be made, it will be proper, in all cases, to let the gases remain together the same definite time (say 10 minutes) before noting the diminution; and it is needless to transfer them into another vessel. If the mixed gas, under examination, contain much more oxygen than is present in atmospherical air, then it is proper to dilute the nitrous gas with an equal bulk of nitrogen or hydrogen gas; and, in this case, the narrower the tube in which the experiment is made, the more accurate will be the result.

Subsequent experience has convinced me that the method, proposed by Mr. Dalton, though sufficiently correct when applied to a mixture of the same, or nearly the same, standard as the atmosphere, cannot be relied on, when the proportion of oxygen is either considerably greater or less. In the former case, the process gives too great a diminution, sometimes indeed to such an extent as to indicate more oxygen gas, than the whole amount of what was submitted to experiment. When the air, on which we are operating, is of an inferior standard to the atmosphere, we do not learn its full proportion of oxygen. Notwithstanding these objections, however, the method has considerable value, since it may be applied to determine the proportion of oxygen in some mixed gases to which other eudiometrical tests are not applicable; for example, to mixtures of hydro-carburet and oxygen gases.

The application of nitrous gas to eudiometrical purposes, it has been observed by Gay Lussac, is susceptible of perfect accuracy, provided certain precautions be observed which he has pointed out, and which were suggested by his theoretical views of the constitution of these gases. A narrow tube he finds to be unfit for an eudiometer, his object being to form a gaseous compound, which is but slowly absorbed by water. Instead therefore of a narrow tube, we must take a wide vessel, such as a small tumbler glass; and to 100 parts of atmospheric air, previously measured, we must add at once 100 measures of nitrous gas. A red fume will appear, which will soon be absorbed without agitation, and in half a minute, or a minute at most, the absorption will be complete. Pass the residuum into a graduated tube, and it will be found, almost invariably, that 84 measures have disappeared. Dividing this number by 4, we have 21 for the quantity of oxygen condensed: and 84 — 21 = 63, gives the nitrous gas absorbed. By an easy calculation it appears that in the new compound 100 vols. of nitrogen must be combined with 167 oxygen, proportions differing from those of all the known compounds of these bases. In this case, also, as Mr. Dana has shown, the anomaly disappears when we find that

	Vol.		Vol.	
one half the oxygen,	= 10.5	with	42	nitrous, forms hypo-nitric acid.
The remainder, -	= 10.5	with	21	nitrous, forms nitrous acid.
	21.		63	

By a series of experiments on mixtures of oxygen and nitrogen gases in various proportions, Gay Lussac satisfied himself that this process may be depended upon, whether the oxygen exceed or fall short considerably of the proportion contained in atmospheric air. My own experience, however, leads me to believe that it is not more worthy of reliance than the use of narrow tubes; and it induces me to prefer other eudiometrical methods, especially combustion with the hydrogen, in every case to which the latter is applicable.

The generation of an acid, by the admixture of nitrous gas with common air or oxygen gas, may be shown by the following experiment. Paste a slip of litmus-paper within a glass jar, near the bottom; and into the jar, filled with and inverted in water, admit as much nitrous gas, previously well washed, as will displace the water below the level of the paper. The colour of the litmus will remain unchanged; but, on admitting atmospheric air or oxygen gas, it will be immediately reddened.

The acid, thus produced, is either nitrous or hypo-nitrous, according to the circumstances of the experiment; the presence of water favouring the production of the latter, and its absence the production of nitrous acid. (Dulong, in Thomson's Annals, x. 39.) The [illegible] the product [illegible] shown, in a [illegible] way, as follows: Into a [illegible], filled with water and inverted in mercury, pass a small quantity of a solution of pure potash, and afterwards, [illegible] of oxygen and nitrous gas [illegible] in the proper proportion. On removing the solution from the tube, exposed [illegible] some time to the atmosphere, and afterward evaporating it, crystals of nitrate of potassa will be formed.

Analysis.—Nitrous gas is decomposed by a red heat, and is resolved into nitrous acid, and two-fifths its volume of nitrogen gas. (Gay Lussac, Ann. de Ch. et de Phys. i. 398.) It is decomposed, also, by almost all bodies that attract oxygen. Thus, iron filings become oxidized, and water, ammonia, and nitrous oxide, in the proportion of one volume from two of nitrous gas, are generated. Sulphuret of potassium, and other sulphurets, have a similar effect. Sulphuret of barium gives half a volume of nitrogen. By mixture with sulphurous acid, nitrous gas is decomposed, and this acid is changed into the sulphuric, but not unless water is present. (Nicholson's Journal, xvii. 43.) Nitrous gas does not compose, with hydrogen gas, a mixture that can be exploded by the electric spark; but with ammoniacal gas it may be fired in a Volta's eudiometer over mercury. The oxygen of the nitrous gas unites with the hydrogen of the ammonia, and the nitrogen of both gases is set at liberty.

Bodies, that have a still more powerful affinity for oxygen, decompose nitrous gas into its *ultimate* elements. Charcoal, ignited in 100 measures, gives 50 measures of nitrogen gas, and 50 of carbonic acid, a gas which, in all cases, contains an equal volume of oxygen. Arsenic, zinc, or potassium, when heated in it, evolve half its volume of nitrogen. Gay Lussac obtained as the mean of three experiments, in which 100 volumes of nitrous gas were decomposed, in two by sulphuret of barium, and in one by tin, 49.5 parts of nitrogen. Nitrous gas consists then of 1 volume of oxygen + 1 volume of nitrogen, neither of which elements is in a state of condensation. We may therefore consider nitrous gas as constituted of

	Vols.	By weight.		
Nitrogen	1	46.60	or	14 = 1 atom.
Oxygen	1	53.40	or	16 = 2 atoms.
Resulting vols.	2	100.	Atomic weight	30

No distinct information is obtained respecting the constitution of nitrous gas by the long continued action of electricity. Dr. Priestley (on Air, vol. i. 2d. Ser. p. 64.) observed that it is rapidly decomposed. One half the azote, according to Mr. Dalton, is liberated, and the remainder unites with the evolved oxygen and composes nitrous acid. (System, p. 334.)

Action of chlorine.—Nitrous gas and chlorine, when both perfectly dry, have no action whatsoever on each other; but, if water be present, there is an immediate decomposition, its hydrogen combining with the chlorine to form muriatic acid, and its oxygen with the nitrous gas to form nitrous acid.

Action of salts of iron.—Nitrous gas is absorbed by the green sulphate and muriate of iron,* which do not absorb nitrogen gas. To ascertain, therefore, how much nitrogen gas a given quantity of nitrous gas contains, let a measured volume of the latter be agitated in a graduated tube with one of these solutions, and the residuum, which is nitrogen, be noted. This analysis is necessary, previously to deducing, from its effects on atmospheric air, the proportion of oxygen gas; for we must subtract from the residuum the quantity of nitrogen introduced by the nitrous gas.

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* For an account of these salts, see chap. ix sect. 16

From the use which is occasionally made in eudiometry of this solution of nitrous gas in sulphate of iron, it may be proper to describe the mode of its preparation.

Dissolve as much of the green sulphate of iron in water as the water will take up, or dissolve iron filings in sulphuric acid, diluted with five or six parts of water, leaving an excess of the iron, in order to ensure the perfect saturation of the acid. Fill a wide-mouthed bottle with this solution, invert it in a cupful of the same, and into the inverted bottle receive the nitrous gas, as it is generated by the proper materials, shaking the inverted bottle frequently. The colour of this solution will be changed to black, and the production of gas and the agitation are to be continued, till the absorption can be carried no farther. The impregnated solution should be preserved in a number of small bottles, not holding more than an ounce or two each. The most commodious method of applying this solution is by means of Dr. Hope's eudiometer, already described.

Of Hypo-nitrous Acid.

1. When 400 measures of nitrous gas and 100 measures of oxygen (in which, taken together, the nitrogen and oxygen are to each other as 100 to 150 in volumes) are mixed together over a solution of potassa confined by mercury, we obtain 200 measures of a compound, called by Gay Lussac *per-nitrous acid.* (Ann. de Chim. et Phys. i. 400.) Mr. Dalton, who obtained it several years ago, and then considered it as nitrous acid, proposed to call it *sub-nitrous acid;* (Thomson's Annals, vol. ix.) but the name *hypo-nitrous* seems to me more conformable to the analogy of similar acids having sulphur and phosphorus for their basis. This new compound is known to us only in combination, or mixed with various proportions of other nitrous compounds. It appears, indeed, to be so unstable, that whenever a stronger acid is added, to expel it from the potassa, the acid is resolved into nitrous gas and nitrous acid.

2. Hypo-nitrous acid is, also, frequently generated, as has already been shown, when nitrous and oxygen gases, or nitrous gas and common air, are mingled together in eudiometrical processes. At the same time nitrous and nitric acids are produced, in proportions to the hypo-nitrous and to each other, which are modified by the circumstances of the experiment. (Dalton, Thomson's Annals, x. 83.)

Lastly, 100 volumes of nitrous gas, exposed for three months to a solution of pure potassa over mercury, were found by Gay Lussac to leave 25 volumes of nitrous oxide. Now deducting from the nitrogen and oxygen, originally contained in the nitrous gas, the quantities constituting 25 of nitrous oxide, we shall find that 25 volumes of nitrogen and 37.5 of oxygen had disappeared, and formed a new compound, which was absorbed by the potassa. Thus

$$\begin{array}{lcrcr} \text{100 Nitrous gas} & = & \text{50 Nitrogen} & + & \text{50 Oxygen} \\ \text{25 Nitrous oxide} & = & 25 & + & 12.5 \\ \hline & & 25 & & 37.5 \end{array}$$

and 25 : 37.5 :: 100 : 150, proportions in the new compound which exactly agree with those assigned by Gay Lussac to hypo-nitrous acid. From these data, if the condensation of elements be equal to the oxygen, the specific gravity of hypo-nitrous acid gas should be 2.6382, common air being unity.

From the evidence of these synthetic processes, it appears to me that there are sufficient grounds for admitting the existence of hypo-nitrous acid as a distinct compound, bearing the same relation to nitrous acid, that hypo-sulphurous acid has to sulphurous acid. It may be considered as constituted of 1 atom of nitrogen (14) + 3 atoms oxygen (24) = 38, or of 1 atom of nitrous gas (30) + 1 atom oxygen (8) = 38.

By the destructive distillation of nitrate of lead, and the condensation of the evolved gas in a receiver surrounded by a freezing mixture, Gay Lussac obtained a liquid consisting principally of this acid. It boiled at 79° Fahr. and was dissipated in very dense red fumes. When poured into water, nitrous gas was disengaged in abundance, and the water was coloured blue, green, or yellow, according to the proportion added. (Ann. de Ch. et de Phys. i. 406.)

Hypo-nitrous acid unites with sulphuric acid, either concentrated or a little diluted, and at a moderate temperature. The compound forms elongated four-sided prisms. These crystals, and even the liquid in which they shoot, give nitrous gas when brought into contact with water. A similar solid is obtained by passing nitrous acid vapour into sulphuric acid; and it appears, also, to be identical with the crystalline solid formed, by Clément and Desormes, by the mixture of oxygen gas, sulphurous acid, nitrous gas, and the vapour of water. The last-mentioned compound has been supposed to consist of nitrous gas and sulphuric acid; but sufficient reasons have been given by Gay Lussac for the new view of it, which has just been stated. It accords also with my own analysis of a compound, formed accidentally in the ventilating pipe of an oil of vitriol chamber, during remarkably cold weather. This I found by a careful analysis, (Ann. of Phil. for May, 1826,) to consist of

Sulphuric acid, -	5 atoms (40 × 5) =	200
Hypo-nitrous acid,	1 atom - - - =	38
Water - - - -	5 atoms (9 × 5) =	45
	Atomic weight	283

Nitrous Acid.

The proportions of the elements of this acid have been investigated by Sir H. Davy. (Elements of Chemical Philosophy.) He concluded that 2 volumes of nitrous gas (= 1 volume of nitrogen + 1 volume of oxygen), and 1 volume of oxygen gas, both freed from moisture, and mixed together in a vessel previously exhausted of air, are condensed into half their volume, and form a deep orange-coloured elastic fluid, which may be called *nitrous acid gas*. Gay Lussac agrees with Davy as to the proportions, but states the condensation at two-thirds of the volume of the mixture. (Ann. de Chim. et Phys. i. 403.) This is coincident with the general law of contraction of volume, according to which, in nitrous compounds, the contraction of volume is equivalent to the oxygen. Two volumes of nitrous gas + 1 oxygen (= 1 nitrogen + 2 oxygen), in all three volumes, should, therefore, constitute 1 volume only of nitrous acid gas.

Gaseous nitrous acid has the following properties:

A taper burns in it with considerable brilliancy. Sulphur when inflamed does not continue to burn in it; but phosphorus burns vividly. Charcoal continues to burn in it with a dull red light. Water absorbs it, and gains a tint of green. It reddens litmus paper, has a sour taste, a strong smell, and turns animal substances yellow.

Dr. Thomson formed this acid, by introducing to 100 measures [illegible] of common air, contained in a cylindrical glass tube 18 inches [illegible] and 0.9 inch diameter, over water, 100 measures of [illegible] The diminution [illegible] amounted [illegible] lumes, and all the oxygen had disappeared. [illegible] periments [illegible] in 100 [illegible] be 20 [illegible] its being [illegible] to [illegible] diminution [illegible] oxygen [illegible] 19.6 [illegible] nitrous [illegible] which [illegible] of oxygen to 42 nitrous, the 2 volumes being [illegible] the air in the water through which the nitrous gas was passed. We have again, therefore, as in the experiment of Davy, two volumes of nitrous gas (= 1 volume of nitrogen and 1 volume of oxygen) uniting with 1 volume of oxygen to form nitrous acid vapour, which must be considered of

1 volume of nitrogen
2 volumes of oxygen } [illegible] 1 volume.

and [illegible] 1 [illegible] of oxygen [illegible] sent [illegible] 1 [illegible] 14, and [illegible] 16.

The specific gravity of this gas [illegible] experiments, [illegible] equivalent to

The specific gravity of nitrous gas × 2 =	[illegible]
Added to the sp. gr. of oxygen .	1.1111
	[illegible]

To form liquid nitrous acid, nothing more had been thought necessary, than to saturate water with nitrous vapour. The water becomes first green, then blue, and finally an orange colour more or less intense. The latter may be brought to the state of green or blue by adding more or less water. Hence the colour depends partly on the circumstance of density; but there can be little doubt that it is materially affected also by the proportions of nitric, nitrous, and hypo-nitrous acids, which, according to Gay Lussac, compose nitrous acid, as thus procured. Dr. Thomson states that it may be obtained in a state of purity by distilling nitrate of lead (First Princ. of Chem. i. 120), but according to Gay Lussac, the resulting product is chiefly hypo-nitrous acid. (Ann. de Ch. et Ph. i. 406.) Dulong first demonstrated that the vapour produced by mixing 2 vols. of nitrous gas with 1 vol. of oxygen, is reducible, by a proper degree of cold, into a true liquid nitrous acid. (Same work, vol. ii.)

The properties of liquid nitrous acid, Berzelius remarks, (13 Ann. de Chim. et de Ph. 10,) differ essentially from those of nitric acid; for while the latter boils at 236°, nitrous acid of the same density boils at 160°. The purely acid part he infers to be composed of 36.9 nitrogen + 63.1 oxygen, but these are the proportions constituting the hypo-nitrous acid of other chemists. With bases, it forms a class of salts, which, he asserts, differ entirely from those containing nitric acid. On the other hand, we have the testimony of Gay Lussac, that the nitrous acid is decomposed with so much facility by contact with alkaline solutions, as to be incapable of forming a distinct class of salts. With solution of potassa, for example, he found that it affords *hypo-nitrite and nitrate*, but nothing that can properly be called a *nitrite*, of potassa. (Ann. de Chim. et Phys. i. 409.) In this case, 2 atoms of nitrous acid, (= 2 atoms of nitrogen + 8 atoms of oxygen) must be decomposed, and the atoms of nitrogen must unite, respectively, with 3 atoms of oxygen to form an atom of hypo-nitrous acid, and with 5 atoms of oxygen to compose an atom of nitric acid.

Nitric Acid.

I. The direct combination of nitrogen and oxygen, affording a decisive synthetic proof of the nature of this acid, may be effected by passing electric sparks through a mixture of nitrogen and oxygen gases. The experiment is an extremely laborious one, and requires, for its performance, a powerful electrical machine; but those who are disposed to repeat it, may proceed as follows:

Let the tube, fig. 84, *c*, be filled with, and inverted in, mercury. Pass into it a portion of atmospherical air, or an artificial mixture of nitrogen and oxygen gases, in the proportion of one of the former to two of the latter.—Let an iron wire, lengthened out with one of platinum, be introduced within the tube, so that the latter metal only may be in contact with the mixed gases; and let the end of this wire be distant about one-fourth of an inch from the extremity of the upper conducting one. When the apparatus is thus disposed, pass a series of electric sparks or shocks through the gases for several hours. The mixture will be diminished in bulk; will redden litmus paper when enclosed in it; and will exhibit distinctly the smell of nitrous acid. If the experiment be repeated, with the addition of a few drops of solution of potassa, in contact with the gases, we shall obtain a combination of nitric (and perhaps hypo-nitrous) acid with that alkali.

This interesting experiment on the generation of an acid, by the direct combination of the elements of the atmosphere, we owe to Mr. Cavendish, who discovered the fact in the year 1785. (Phil. Trans. lxxv.) The proportions, which he found to be necessary for mutual saturation, were five parts of oxygen gas and three of common air, or seven parts of oxygen gas to three of nitrogen gas. The acid, thus obtained, being constituted of 100 measures of nitrogen + 233 oxygen, appears therefore to have been intermediate between nitrous and nitric acid, or rather to have consisted of both those acids in a state of mixture. No evolution either of light or heat attends this combination, which is very slowly and gradually effected.

Nitric acid, then, is to be considered as a gaseous body, capable of existing in a liquid form, but only when it is combined with water. According to the experiments of Sir H. Davy, published in 1800, it is composed, in 100 grains, of 29½ azote, and 70½ oxygen. This approximation differs but little from the proportions deducible from the synthetic experiments of Cavendish, *viz.* 27.8 nitrogen to 72.2 oxygen. The subsequent results of Davy led him, however, to believe, that 4 in volume of nitrous gas and 2 of oxygen gas, when condensed in water, absorb 1 additional volume of oxygen to become nitric acid. We have then 2 volumes of oxygen (contained in 4 of nitrous gas) + 2 + 1 = 5 volumes of oxygen, to 2 of nitrogen, or 2½ volumes of oxygen to 1 of nitrogen, for the constituents of nitric acid in a gaseous state. Estimating the oxygen gas, existing in nitrous gas, at one-half its volume, and taking the specific gravities of oxygen and nitrogen gases at the numbers already given, 100 parts by weight of nitric acid must consist of

Oxygen - -	74.13 - - - - - - -	40 = 5 atoms.
Nitrogen - -	25.87 - - - - - - -	14 = 1 atom.
	100.	Atomic weight 54

In investigating what number should be used as the equivalent of nitric acid, Dr. Wollaston was led to inquire into the composition of that acid; and, from his own experiments, and those of Richter and Phillips, he deduced the oxygen, which nitric acid contains, to be by weight to the nitrogen as 50 to 17.54; a proportion so nearly agreeing with that of 40 to 14, that we may now consider the atomic constitution of nitric acid as truly represented by those numbers, added together; and, in volumes, by 1 vol. of nitrogen, and 2½ vols. of oxygen, occupying the space of 1 vol. By the careful decomposition of nitrate of baryta by charcoal at a red heat, I have actually obtained gases, fully establishing those proportional volumes for the elements of nitric acid. (Ann. of Phil. N. S. viii.

299.) The specific gravity of nitric acid gas, which can only be got by calculation, will be,

$$\begin{array}{lr} 2\tfrac{1}{2} \text{ volumes of oxygen} = 1.111 \times 2.5 = & 2.7775 \\ 1 \text{ volume of nitrogen - - - - - - -} & .9722 \\ \hline & 3.7497 \end{array}$$

The formation of liquid nitric acid, by the direct union of oxygen and nitrogen gases, or even by condensing oxygen and nitrous gases into water, is a process too tedious to be practicable on the large scale. The following is the method commonly employed for obtaining liquid nitric acid for use.

Process for preparing Liquid Nitric Acid.

The apparatus best adapted for preparing nitric acid is a glass retort, which may be either tubulated or not; but in the latter case the sulphuric acid must be poured upon the nitre, coarsely powdered, through a retort funnel, (plate i. fig. 10,) with care, to prevent any of it from adhering to the inner surface of the neck. A tubulated receiver, of large capacity, is to be applied, between which and the retort an adopter may be interposed; these junctures being luted with a mixture of pipe-clay, sifted sand, and cut tow or flax. To the tubulure of the receiver, a glass tube may be fixed by means of the fat lute, and may terminate in another large receiver, containing a small quantity of water.

If the operator wishes to collect the gaseous products, also, this second receiver should be provided with a tubulure, to which a bent pipe may be luted, terminating under one of the inverted funnels in the shelf of the pneumatic trough. When heat is applied to the retort, through the intervention of a sand-bath, the first product, that passes into the receiver, is generally of a red colour, and of a smoking quality. These appearances gradually diminish; and, if the materials used were clean, the acid will come over pale, and almost colourless. Afterwards it gradually re-assumes a red colour, and smoking property. These appearances go on increasing till the end of the operation; and the whole product, mingled together, has either a yellow or an orange colour, according to the temperature employed.

The proportions, recommended in the London Pharmacopœia for the preparation of nitric acid, are two pounds of nitrate of potassa, deprived by heat of its water of crystallization, and two pounds of sulphuric acid. These are directed to be mixed in a glass retort, and distilled in a sand-bath, until a red vapour arises. The acid in the receiver is to be mixed with an ounce of nitre, and again distilled in a similar manner. After the second distillation, its specific gravity is 1.500; and 100 grains are saturated by 212 of crystallized subcarbonate of soda. The rectification Mr. Phillips considers as unnecessary. The expediency of using twice the quantity of acid required to neutralize the alkali of the nitre, he explains by the fact that the nitric acid yielded by an atom of nitre requires, for its perfect condensation into a liquid, two atoms of water, which cannot be furnished by less than two atoms of sulphuric acid. The quantity of the latter acid may be reduced, and the same effect obtained, if water be put into the receiver; as is done by those who prepare the nitric acid for manufacturing purposes. With whatever care the process is conducted, there is still some loss, and Mr. Phillips has never been able, from 24 ounces of nitre, which ought to give 16 oz. 1 dr. 2 sc. of liquid acid of sp. gr. 1.5, to obtain more than 15 oz. 6 dr. The deficiency, amounting to 3 dr. 2 sc., must be ascribed to the decomposition of the acid into its elements during distillation. (Transl. of the London Pharm. p. 28.)

The nitric acid which first passes over has the greatest specific gravity. In an experiment of Dr. Perceval of Dublin, the product was taken in three portions; the first of which had the specific gravity of 1.494, the second of 1.485, and the third of 1.442. (Trans. of the Irish Academy, iv. 37.) Gay Lussac, by two successive distillations of nitric acid of sp. gr. 1.3 from four times its weight of sulphuric acid, brought it to the density of 1.510. In this state he found it to be decomposed by heat or light with extraordinary facility. (Ann. de Chim. et de Phys. vol. i.) According to Dr. Thomson, by using only 6⅛ parts of concentrated sulphuric acid to 12¼ parts of pure anhydrous nitre, the acid which comes over is the strongest that can be procured, and has the specific gravity of about 1.554.

In the large way, and for purposes of the arts, it is usual to substitute earthen or cast-iron retorts, made extremely thick, for those of glass. An earthen head is adapted, and this is connected with a range of proper condensers. The strength of the product is varied also by putting more or less water into the receiver. What is called *double aqua fortis* varies in its specific gravity from 1.3 to 1.4.

Nitric acid, obtained by this process, is seldom perfectly pure. It may contain both sulphuric and muriatic acids; the former of which is indicated by a white precipitate, on adding a solution of nitrate of baryta to a little of the acid diluted with eight or ten parts of water; and the latter by a milkiness produced by nitrate or sulphate of silver. The sulphuric acid, if present, may be separated, either by a second distillation from a portion of very pure nitre, equal in weight to one-eighth of that originally employed, or by adding solution of nitrate of baryta; allowing the precipitate to settle; decanting the clear liquid, and distilling it. Muriatic acid is separated by the addition of nitrate of silver. An immediate milkiness ensues, and fresh additions must be made of nitrate of silver, as long as it occasions this appearance. Then allow the precipitate to subside; decant the clear liquid, and re-distil it; leaving one-eighth or one-tenth in the retort. The product will be pure nitric acid. Nitrate of lead may be substituted for nitrate of silver. The nitric acid may be obtained at first free from muriatic acid, if perfectly pure nitre be employed for distillation. This purification is effected by repeated solutions of the nitre in boiling distilled water, and re-crystallizations, till the crystals, dissolved in water, no longer precipitate nitrate of silver.

Nitric acid, obtained in this manner, generally holds in solution a considerable quantity of nitrous gas or nitrous acid. An excellent test of the presence of even very small proportions of *nitrous* acid has been discovered by Gay Lussac in the solution of red sulphate of manganese, which is instantly deprived of colour by that acid, but not by perfect *nitric* acid. To expel the former, put the acid into a retort, to which a receiver is applied, the two vessels not being luted, but joined merely by paper. Apply a very gentle heat for several hours to the retort, changing the receiver as soon as it becomes filled with red vapours. The nitrous acid will thus be expelled, and the nitric will remain in the retort in a state of purity, and as limpid and colourless as water. It must be kept in a bottle carefully secluded from the light.

Properties of Liquid Nitric Acid.

The liquid nitric acid has the following properties:

Hydro-nitric acid is perfectly limpid and colourless, and emits white fumes when exposed to the air. It gives a yellow stain to the skin, and acts powerfully on animal substances.

Specific gravity.—It is heavier than water, and its specific gravity varies with the process employed in preparing it. Proust obtained it as high as 1.62; and the specific gravity of real nitric acid, which cannot, however, be obtained separately, has been calculated at 1.75. (Dalton, p. 355.) In its strongest form, each atom is united with an atom of water, which is essential to its existence in a liquid state, and without which its elements would separate from each other. In acid of the sp. gr. 1.50, the water amounts, calculating from the data furnished by Dr. Wollaston, to 25.11 grains in 100 grains of acid; or, according to Mr. Phillips, to 25.09, equivalent to 1 atom acid + 2 atoms of water. According to Sir H. Davy, the strongest acid (sp. gr. 1.55) contains 14.4 parts of water in 100; and acid of sp. gr. 1.42 contains 25.2 of water in 100. (Elem. p. 365.) Dr. Thomson (First Princ. of Chem. i. 113,) by using, in the decomposition of anhydrous nitric, only half its weight of concentrated sulphuric acid, obtained nitre acid of sp. gr. 1.534. From an analysis of this, he infers that acid of sp. gr. 1.55 is a compound of 1 atom of acid and 1 atom of water, or it contains

Real acid	- -	85.714 parts	- -	54
Water	- -	14.286	- -	9
		100.		63

When the full quantity of sulphuric acid was used, *viz.* 12¼ parts to 12¾ anhydrous nitre, he found the sp. gr. of the product only 1.4855, and that it is a compound of 1 atom real acid and 2 atoms of water. The following Table he derived from experiments, made by adding given quantities of water to acid of sp. gr. 1.4855, and taking the specific gravity of the mixtures.

Table of the Composition of Nitric Acid of Different Densities.

Atoms of Acid.	Atoms of Water.	Acid in 100.	Specific Gravity.
1	1	85.714	1.55
1	2	75.000	1.4855
1	3	66.668	1.4546
1	4	60.000	1.4237
1	5	54.545	1.3928
1	6	50.000	1.3692
1	7	46.260	1.3456
1	8	42.857	1.3220
1	9	40.000	1.3032
1	10	37.500	1.2844
1	11	35.294	1.2656
1	12	32.574	1.2495
1	13	31.579	1.2334
1	14	30.000	1.2173
1	15	28.571	1.2012

Mr. Phillips, in one instance, obtained, from equal weights of nitre and sulphuric acid, sp. gr. 1.8442, nitric acid of a yellow colour, with a tint of red, which from the quantity of carbonate of lime dissolved by it, appeared to consist of 80 real acid and 20 water in 100, or of 2 atoms of acid united with 3 atoms of water. (Ann. of Phil. Dec. 1827.)

As a practical rule for determining the quantity of real nitric acid by the marble dissolved, Mr. Faraday multiplies by 1.08 the number of grains of marble dissolved by a given weight of acid of any density. The product shows the weight of real acid. Care must, of course, be taken that the full action of the acid has been exerted on the marble before noting its loss of weight.

Effect of temperature.—Nitric acid boils at 248° Fahr., and may be distilled over, without any essential change. This, however, is true only of acid of the specific gravity 1.4237; for an acid, weaker than this, is strengthened by being boiled; while an acid, stronger than 1.4237, becomes weaker by boiling. All the varieties of nitric acid, therefore, are brought, by sufficient boiling, to the specific gravity 1.4237, which appears to be the most energetic combination of acid and water. From the foregoing Table, it will be seen that it is then constituted of 1 atom real acid, and 4 atoms of water.

Hydro-nitric acid may be frozen by a sufficiently low temperature. Like sulphuric acid, it has a certain point of density at which it most readily congeals. Mr. Cavendish has described this, not by its specific gravity, but by the quantity of marble which it is capable of dissolving. When it takes up $\frac{418}{1000}$ths of its weight, in which case its specific gravity is 1.3, the acid freezes at 2° below 0 Fahrenheit. When considerably stronger and capable of dissolving $\frac{561}{1000}$ths, it required cooling to — 41.6, and when so much diluted as to take up only $\frac{276}{1000}$ths, it did not congeal till cooled to —40.3. (Phil. Trans. 1788.)

Test of the presence of nitric acid.—Liebig, finding the known tests of nitric acid not satisfactory in all cases, has proposed the following: Mix the liquid under examination with just as much solution of indigo in sulphuric acid as will impart a distinct blue colour, then add a few drops of sulphuric acid, and boil the mixture. If any nitrate be present, the liquid will be bleached, or, if the quantity of nitrate be very small, will be turned yellow. In this way, also, nitric acid may be detected, though diluted with 400 times its weight of water. Or, by adding a little chloride of sodium to the liquid before applying heat, $\frac{1}{100}$th part of nitric acid may be discovered. (Quart. Journ. July 1827, p. 204.)

Relation to water.—Strong hydro-nitric acid absorbs moisture from the atmosphere; in consequence of which it increases in weight, and diminishes in specific gravity.

When two parts of the acid are suddenly diluted with one of water, each at 58°, an elevation of temperature is produced to about 120° Fahrenheit; and the admixture of 58 parts by weight of acid of specific gravity 1.50 with 42 parts of water, both at 60° Fahrenheit, gives a temperature of 140°. (Ure, Quart. Journ. iv. 208.) When more water is added to this diluted acid, its temperature is reduced. Snow or ice, added to the cold diluted acid, is instantly liquefied, and an intense degree of cold is produced.

Action of light.—When very concentrated, liquid nitric acid becomes coloured by exposure to the sun's light, passing first to a straw colour, and then to a deep orange. This effect is produced by the union of the light of the sun with oxygen, in consequence of which the proportion of that principle to the nitrogen is diminished.

By exposing it to the sun's rays in a gas bottle, the bent tube of which terminates under water, oxygen gas may be procured.

Action of combustibles.—This acid retains its oxygen with but little force.—Hence it is decomposed by all combustible bodies, which are oxygenized by it with more or less rapidity in proportion to their affinity for oxygen.

1. When brought into contact with hydrogen gas at a high temperature, by transmitting them together through an ignited porcelain tube, a violent detonation ensues. This experiment, therefore, requires great caution. Dr. Priestley found also that hydrogen gas, after being used to displace nitric acid from a bottle inverted in that liquid, had become explosive. 2. Poured on perfectly dry and powdered charcoal, it excites the combustion of the charcoal, which becomes red-hot, and emits an immense quantity of fumes. 3. It also inflames essential oils (as those of turpentine and cloves), when suddenly poured on them. In these experiments, the acid should be poured out of a bottle, tied to the end of a long stick; otherwise the operator's face and eyes may be severely injured. 4. Nitric acid is decomposed by boiling it in contact with sulphur, which attracts the oxygen, and forms sulphuric acid.

The hydro-nitric acid is also decomposed by metals; as iron, tin, zinc, copper, &c. with different phenomena, according to the affinity of each metal for oxygen. This may be seen by pouring some strong nitric acid on iron filings, or powdered tin. The acid must be of greater density than 1.48, otherwise it will not produce the effect. Violent heat, attended with red fumes, will be produced, and the metals will be oxidized.

Absorption of nitrous gas.—Liquid nitric acid absorbs nitrous gas, and undergoes a considerable change of colour and properties. The gas may be transmitted, as it issues from the materials that afford it, through a quantity of colourless nitric acid, which first passes to straw yellow, and becomes gradually deeper in its colour, till at length it assumes a deep orange, and emits red-coloured fumes. According to Dr. Priestley (on Air, 2d edit. i. 383), 100 parts of nitric acid of specific gravity 1.4 absorb in two days 90 parts by weight of nitrous gas.* Seven parts of gas, he states, are sufficient to give the acid an orange hue; when 18 have been absorbed, it becomes green; and, when it has taken up all that it is capable of condensing, it emits an immense quantity of red fumes. The gas thus absorbed may be expelled again by a gentle heat, or by diluting the acid with water.

Sir H. Davy, in the year 1800, gave the following table, showing the proportion of nitrous gas in nitrous acid of different colours.

		100 parts by weight contain.		
	Sp. Gr.	Real Acid.	Nit. Gas.	Water.
Pale yellow	1.502	90.5	1.2	8.3
Bright ditto	1.50	88.94	2.96	8.1
Dark orange	1.480	86.84	5.56	7.6
Light olive	1.479	86.	6.45	7.55
Dark olive	1.478	85.4	7.1	7.50
Bright green	1.476	84.8	7.76	7.44
Blue green	1.475	84.6	8.	7.40

Mere dilution with water is sufficient to vary these colours. Thus the dark orange-coloured acid, by dilution, passes through the shades of blue, olive, and bright green. Nitric acid, also, by absorbing nitrous gas, has its specific gravity dimininished.

Nitro-Muriatic Acid, or Aqua Regia.

This acid may be formed by mixing two parts by weight of nearly colourless nitric acid with one of liquid muriatic acid. Proust employs only one of nitric to four of muriatic acid. Though the acids are both perfectly pale, yet the mixture becomes of a deep red colour, a brisk effervescence takes place, and pungent vapours of chlorine are evolved. Dr. Priestley found that the most powerful aqua regia is produced by impregnating muriatic acid with nitrous acid vapour; but he did not succeed in his attempt to reverse the process by impregnating nitrous acid with muriatic acid gas.

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* There appears to be some error in this statement, for, according to Sir H. Davy, 100 parts of nitric acid, when saturated with nitrous gas, hold only 9 or 10 of the latter; and, into acid of sp. gr. 1.3, Mr. Dalton could not condense above 20 times its bulk, or a little more than 2 per cent. by weight.

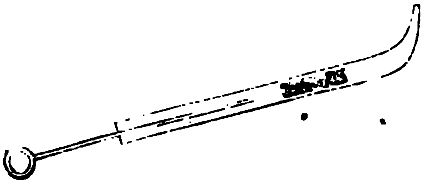
Considerable light has been thrown on the nature of this acid by the experiments of Sir H. Davy, (Quart. Journ. i. 67,) who has rendered it probable that its peculiar properties are owing to a mutual decomposition of the nitric and muriatic acids, the oxygen of the former uniting with the hydrogen of the latter, in consequence of which water, chlorine, and nitrous acid are the results. For every 101 parts in weight of real nitric acid (equivalent to 118 of hydro-nitric acid) which are decomposed, 67 parts of chlorine, he calculates, are produced. According to this view, it is not correct to say that *aqua regia* oxidates gold or platinum, since it merely causes their combination with chlorine. By long continued and gentle heat, nitro-muriatic acid may be entirely deprived of chlorine, and it then loses its power of acting on gold and platinum.

The nitro-muriatic acid does not form, with alkaline or other bases, a distinct genus of salts, entitled to the name of nitro-muriates; for, when combined with an alkali, or an earth, the solution yields, on evaporation, a mixture of a muriate and a nitrate; and metallic bodies dissolved in it yield muriates only. The most remarkable property of nitro-muriatic acid (that of dissolving gold, from whence it has been called *aqua regia*) will be described in the chapter on that metal.

Combination of Nitrogen with Chlorine.

Chlorine has no action whatsoever on nitrogen gas, nor on nitrous gas or nitrous oxide, when both gases are perfectly dry; but a compound of chlorine and nitrogen may be formed, by passing chlorine gas through a solution of nitrate of ammonia, or of almost any ammoniacal salt, of the temperature of 80° to 90° Fahrenheit. The chlorine gas is rapidly absorbed, and a film appears on the surface, which soon collects into yellowish drops, that sink to the bottom of the liquor.

Mr. Brande recommends, as the simplest method of forming it, to fill a perfectly clean glass basin with a solution of about one part of sal ammoniac in twelve of water, and to invert into it a tall jar of chlorine gas. The saline solution gradually rises into the glass, a film forms upon its surface, and it acquires a deep yellow colour. At length small globules, resembling yellow oil, collect upon its surface, and successively fall into the basin beneath, from whence they are most conveniently removed by drawing them into a small and perfectly clean glass syringe, made of a glass tube drawn to a



pointed orifice, and having a copper wire, with a little tow wrapped round it for a piston. In this way a globule may be drawn into the tube, and transferred to any other vessel.

This yellowish and oily fluid is the most powerfully detonating compound with which we are acquainted. When gently warmed, it explodes with so much violence, that it is not safe to employ a quantity larger than a grain of mustard seed. Its discoverer, M. Dulong, was severely wounded in his first experiments on this substance, (Ann. de Chim. vol. 85,) and Sir H. Davy had a serious injury done to his eyes in repeating them. It is expedient, therefore, to proceed with great caution.

When a globule of this fluid is thrown into olive oil, turpentine, or naphtha, it explodes even without heat, and so violently, as to shatter any glass vessel. The same effect ensues when it touches phosphorus or phosphorized alcohol or ether; but pure alcohol and carburet of sulphur deprive it of its explosive property.

The specific gravity of the fluid, Sir H. Davy has determined to be 1.653, water being 1. (Phil. Trans. 1813.) It is not congealed by exposure to the cold produced by snow and muriate of lime.

Messrs. Porrett, Wilson, and Kirk, have published an elaborate memoir on this compound in Nicholson's Journal, xxxiv. 180, and have described at great length the appearances attending its formation, and the results of acting upon it with a great variety of substances. These experiments tend to show that it will not explode at any temperature much under 212° Fahr. nor without the contact of a combustible body; that it may be distilled at or below 160°, and does not become solid at —16°. Though the class of bodies termed combustible act upon it most remarkably, yet there are some bodies of that description, camphor for instance, with which it seemed to unite without decomposition; nor did the metals, resins, or sugar, cause it to explode. It detonated with the following only, out of 125 substances that were tried.

Supersulphureted hydrogen.
Phosphorus.
Phosphuret of lime.
Caoutchouc.
Myrrh.
Palm oil.
Ambergris.
Whale oil.
Linseed oil.
Olive oil.
Ditto camphoreted.
Ditto sulphureted.
Oil of tar.
Oil of amber.
Oil of petroleum.
Oil of orange peel.
Naphtha.
Metallic soaps.
Fused potassa.
Solution of ammonia.
Phosphureted hydrogen gas.
Nitrous gas.
Phosphureted camphor.
Oil of turpentine.

The products of its detonation are chlorine and nitrogen gases, but it is impossible to determine the bulk of those elements which are afforded by a given weight. The best method of analyzing it is by its action on mercury, which unites with the chlorine, and sets the nitrogen free. From various experiments of this kind, Sir

H. Davy concludes that it is composed of four in volume of chlorine to one in volume of nitrogen, or of

Chlorine - - - - - - - -	91.2
Nitrogen - - - - - - - -	8.8
	100.

These proportions correspond best with the opinion, that it is constituted of one atom of nitrogen to four atoms of chlorine; it will be represented therefore by 14 + (36 × 4 =) 144, making together 158; but its analysis is not sufficiently correct to render these numbers worthy of implicit reliance.

Of the compound of Nitrogen with Iodine.

Iodine cannot be brought to act directly upon nitrogen, but, when iodine is kept in a solution of ammonia in water, it is gradually converted into a brownish black substance, which is an *iodide* of *nitrogen.* This may be collected, and dried at a very gentle heat on bibulous paper.

This compound evaporates spontaneously in the open air. It explodes with great violence when touched or when heated, and is converted into nitrogen gas and iodine, but all attempts to collect the products have failed, and we are ignorant, therefore, of the proportion of its components. From the experiments of Colin, as well as from theoretical considerations, Gay Lussac believes that it consists of 3 atoms of iodine and 1 atom of nitrogen.

SECTION III.

Of Carbon, and its compounds with Oxygen, Chlorine, and Iodine.

Charcoal, in the form under which it ordinarily occurs, procured by igniting wood in close vessels, contains several ingredients that are not essential to it; and it is to the pure carbonaceous principle, divested of these impurities, that the term *Carbon* is alone properly applied. The diamond, which Sir I. Newton had sagaciously inferred to be a combustible body, from its powers of refracting light, was first shown by Guyton to contain carbon, and his experiments led him to conclude that the diamond is the only form of pure carbon; and that charcoal is a compound of carbon and oxygen, or an oxide of carbon. (Annales de Chimie, xxxi.) The experiments of Messrs. Allen and Pepys have, however, gone far towards proving that the diamond and charcoal, though so widely remote from each other in external characters, are, as to their chemical nature, identically the same; and that the difference between them, in all probability, results merely from the respective states of aggregation of their particles.

Some doubts, it must be confessed, were thrown on this conclusion by an experiment of Sir H. Davy, in which an inflammable gas was obtained, by igniting charcoal in a Toricellian vacuum, by a powerful Voltaic battery. But the hydrogen, thus evolved, may reasonably be ascribed to water, from which it is extremely difficult, if not impossible, to free charcoal. The absence of oxygen from charcoal was proved, by heating it with potassium, for no potassa was produced; but when potassium was heated with diamond, there was an indistinct appearance of the production of that alkali. (Phil. Trans. 1814, p. 557.) The subsequent experiments of the same philosopher tend to establish, that charcoal invariably contains either hydrogen or water; for when it is burned in pure and dry oxygen gas, some moisture is always deposited. The quantity, however, is so small, that hydrogen cannot exist in charcoal as an essential ingredient, or in any definite proportion. The diamond appears to be absolutely free both from water and hydrogen; and it is in this respect only, and in the mechanical arrangement of its particles, that we have any evidence of its differing from charcoal. If proof were wanted of the identity of the two substances, it is furnished by the fact that the diamond converts iron into steel, under circumstances quite free from all sources of fallacy. (Phil. Trans. 1815, p. 371.)

To obtain charcoal, pieces of oak, willow, hazel, or other woods, deprived of the bark, may be buried in sand in a crucible, which is to be exposed, covered, to the strongest heat of a wind-furnace. For purposes of accuracy, charcoal must be used when recently prepared, and before it has had time to become cold; or if it cannot be had fresh made, it must be heated again to redness under sand in a crucible. A remarkably pure charcoal may be obtained by passing the vapour of oil of turpentine, or of spirit of wine, through a red-hot tube. It then appears in the form of a black impalpable powder. In the experiments of Sir H. Davy, this sort of charcoal, by combustion in oxygen gas, gave a much smaller product of moisture than any other.

From 100 parts of each of the following woods Messrs. Allen and Pepys obtained the annexed quantities of charcoal: *viz.*, from fir, 18.17; lignum vitæ, 17.25; box, 20.25; beech, 15; oak, 17.40; mahogany, 15.75. Experiments on the proportions and specific gravities of charcoal, obtained from different kinds of wood, are exhibited also in the form of a table by Mr. Griffiths, in the Quarterly Journal, xvi. 264, and in another table by [illegible]rsten, Phil. Mag. and Ann. of Phil. Sept. 1827.

In the large way, charcoal is now most commonly prepared in this country by the distillation of wood in cast-iron cylinders. The loppings of young trees, commonly called crop-wood, are generally employed: and, besides the charcoal, liquid products of value are collected, especially an impure vinegar which will be described in vol. ii., called *pyroligneous* [illegible]. The process is described at length by Mr. Parkes in the 2d volume of his "Chemical Essays," p. 271.

The charcoal of wood, besides its use as a fuel, is necessary to the preparation of that kind of iron which is used for wire; to the cementation of steel by the common process; and to the preparation of gunpowder. The charcoal prepared from coal, called *coke*, is less pure, and, beside other substances, generally contains sulphur; but it has the advantage of being heavier and more compact, in consequence of which it is better adapted for burning in furnaces in which there is a powerful blast of air.

Lamp-black, a necessary ingredient of printing-ink, is the condensed soot collected from the refuse resin of turpentine makers.

A new and very curious form of carbon has been described by Dr. Colquhoun of Glasgow (Ann. of Phil. July 1826). When coal gas is passed over red-hot iron, in Mr. Macintosh's process for converting iron into steel, this variety of carbon is deposited in long capillary threads, very fine, brittle, perfectly black, and having considerable lustre. In its external appearance, though this is the most perfect, many shades of difference occur. The filaments are combustible, without leaving any residuum, and on being burned with peroxide of copper afford carbonic acid only, and give no trace of hydrogen; nor do they, by treatment with the proper tests, exhibit the presence of iron. They may be considered, therefore, as absolutely pure carbon.

Charcoal has the following properties:

1. In its aggregated state it is black, perfectly insipid, and free from smell; insoluble in water, brittle, and easily pulverized. In close vessels, and entirely secured from contact with air, it is unchanged by any degree of heat. A gas, however, may be collected from it by distillation, which consists of hydrogen and carbon, and perhaps a little oxygen. Berthollet has found, also, in the aëriform products of its distillation, a considerable proportion of nitrogen. (Mémoires d'Arcueil, ii. 484.)

In the section on carbonic acid, it will be explained what is meant by the *vapour* of *charcoal*, and it may be sufficient at present to observe that this term is not applicable to charcoal in any state in which it can be experimentally exhibited, but to that state in which it exists in gaseous combination with other bodies.

2. Charcoal has the singular property of absorbing gases without alteration. Fill a jar with common air, or any other gas, and place it over dry mercury: take a piece of charcoal, red-hot from the fire, and plunge it in the mercury of the bath: when cold, let it be passed into the vessel of gas, without bringing it into contact with the atmosphere. A considerable diminution of the gas will be effected; and in 24 or 36 hours its absorption will be completed.

Count Morozzo has given the following table of the quantities of different gases, absorbed in the foregoing manner by charcoal. In each experiment, he employed a piece of that substance 1 inch long and $\frac{3}{4}$ of an inch diameter. The receiver containing gas was 12 inches long and 1 inch diameter.

Gas absorbed.	Inches.	Gas absorbed.	Inches.
Atmospheric air - - -	$3\frac{1}{2}$	Nitrous - - - - - -	$6\frac{5}{8}$
Carbonic acid - - - -	11	Hydrogen - - - - -	$2\frac{1}{12}$
Ammonia - - - - -	11	Oxygen - - - - - -	$2\frac{1}{4}$
Muriatic acid - - - -	11	Sulphurous acid - - -	$5\frac{1}{2}$
Sulphureted hydrogen -	11		

This property of charcoal has been made the subject of a valuable set of experiments by Saussure. (Thomson's Annals, vi. 241.) Charcoal of box wood he found to absorb, in less than 24 hours, of

	Vols.		Vols.
Ammoniacal gas - - - -	90	Olefiant gas - - - - -	35
Muriatic acid - - - -	85	Carbonic oxide - - -	9.42
Sulphurous acid - - -	65	Oxygen - - - - - - -	9.25
Sulphureted hydrogen -	55	Azote - - - - - - -	7.5
Nitrous oxide - - - -	40	Hydrogen - - - - - -	1.75
Carbonic acid - - - -	35		

Most of the phenomena attending this absorption have already been described, in speaking of the absorption of gases by solids. It appears to be entirely a mechanical effect; for even those gases that have an affinity for charcoal (hydrogen and oxygen for instance), are given out unchanged at the heat of boiling water. The densest and heaviest kinds of charcoal are most remarkable for this property, which is much diminished by pulverizing them; and it does not exist at all in plumbago or in stone coal.

3. From the experiment of Rouppe, (Ann. de Chim. xxxii. 1,) it appears, that if charcoal, which has imbibed oxygen gas, be brought into contact with hydrogen gas, water is generated; but Saussure, by a careful repetition of it, could not obtain the same result.

4. Charcoal, by long exposure to the atmosphere, absorbs one-twentieth of its weight, three-fourths of which are water. (Clement and Desormes.)

The charcoal of different woods, Messrs. Allen and Pepys found to increa[illegible]y differently in weight; that from fir gained by a week's exposure to the air, 13 per cent.; that from lignum vitæ, in the same time, 9.6; from box, 14; beech, 16.3; oak, 16.5; mahogany, 18. The absorption goes on most rapidly during the first 24 hours; and by much the largest part of what is absorbed consists of water merely.

5. Charcoal resists the putrefaction of animal substances. A piece of flesh-meat, which has begun to be tainted, may have its sweetness restored by rubbing it daily with powdered charcoal; and may be preserved sweet for some time by [illegible]ing it in powdered charcoal, which is to be renewed daily. [illegible]trid water is also restored by the application of the same substance; and water may be kept unchanged at sea, by perfectly charring the inner surface of the casks which are used to contain it. (Lovitz, Ann. de Chim. tom. xiv.) It produces, also, a remarkable effect in destroying the taste, odour, and colour of many vegetable and animal substances. Common vinega[illegible] being boiled on it, is rendered perfectly limpid. Rum and [illegible] varieties of ardent spirit, which are distinguished by peculiar colours and flavours, lose both by macer[illegible]n with powdered charcoal. The colour of litmus, indigo, [illegible] pigments, dissolved or suspended in water, is destroyed. [illegible] animal fluids, and air contaminated with offensive fumes, [illegible] completely deprived of their odour. These effects are

most certainly produced by animal charcoal; which is best adapted for this purpose when obtained by calcining bones in close vessels. (79 Ann. de Chim. 80; Quart. Journ. iv. 367.)

6. Charcoal is a very slow conductor of caloric. The experiments of Guyton have determined, that caloric is conveyed through charcoal more slowly than through sand, in the proportion of three to two. Hence powdered charcoal may be advantageously employed to surround substances which are to be kept cool in a warm atmosphere; and also to confine the caloric of heated bodies. It affords, however, an easy transmission to the electric fluid.

7. *Fusion and Volatilization of Charcoal.*—Professor Silliman, of Yale College, America, was the first who observed, on subjecting cylindrical pieces of charcoal, tapered to a point, to the *galvanic deflagrator* of Dr. Hare, when in powerful action, that the charcoal point of the positive pole instantly shot out $\frac{1}{10}$th, $\frac{1}{8}$th, or even $\frac{1}{4}$th of an inch. The charcoal of the negative pole underwent, in the mean time, a change precisely the reverse, its point disappearing, and a crater-shaped cavity being substituted in its stead. By placing a piece of metal at the negative pole in lieu of charcoal, it was ascertained by the absence of the usual phenomena, that the increase, before observed in the charcoal at the positive pole, was occasioned by an actual transference of charcoal, from the former to the latter. On examining with a magnifier the projecting point of the charcoal at the positive pole, it was found to have undergone distinct fusion into small spheres collected into botryoidal or mamillary concretions. (Ann. of Phil. N. S. iv. 119.)

These experiments have been repeated, with similar results, by Professor Griscom of New-York. (Silliman's American Journal, v. 361.) But considerable doubts have been expressed as to their accuracy, by Mr. Vanuxem, who, while he admits the facts to be correctly stated, ascribes the appearance of fusion to foreign substances, which, indeed, he detected in the fused globules by analysis. By operating on charcoal in the purer form of lamp-black, he could not obtain any appearances of fusion. Dr. Colquhoun, on the other hand, inclines to the opinion that the charcoal, deposited from coal gas, has undergone fusion, notwithstanding its freedom from foreign bodies.

8. The weight of the atom of charcoal was inferred by Mr. Dalton to be 5.4, that of oxygen being 7. But if the weight of the atom of oxygen be corrected to 8, the atom of charcoal will then weigh 6. The evidence in favour of this conclusion will be stated in the following section. The specific gravity, which carbon would have, if reducible into a vaporous form, is calculated by Gay Lussac to be 0.4166, a number adopted by Dr. Thomson.

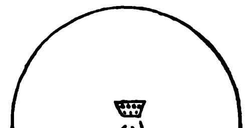
Combustion of Carbon.

If a small piece of charcoal be exposed red-hot to atmospheric air, it exhibits scarcely any signs of combustion, and soon becomes cold; but Sir H. Davy has observed that dry charcoal converts oxygen gas pretty rapidly, though imperceptibly, into carbonic acid, at a temperature a little above the boiling point of quicksilver, (Phil. Trans. 1817, p. 16,) and, according to Saussure, the oxygen gas, which is absorbed by charcoal, is converted in time into carbonic acid, at the common temperature of the atmosphere. If a piece of charcoal, heated to about 800° or 1000° Fahrenheit, or nearly to redness, be introduced into a receiver filled with oxygen gas, it continues to burn with greatly increased splendour, and with bright scintillations; and if the charcoal be pure, and its proportion rightly adjusted, it is entirely consumed. When the quantity burnt is considerable, a manifest production of water takes place, and the inner surface of the glass vessel becomes covered with moisture, which disappears, however, on standing. This portion of water owes its origin to the union of oxygen with the hydrogen, which, it appears from Sir H. Davy's experiments and from the results of its distillation, all charcoal contains.

The diamond, also, which was formerly considered as an incombustible substance, may be burnt by a sufficiently intense heat even in atmospherical air. The Florentine academicians, in the year 1694, appear first to have ascertained this fact, by exposing diamonds to the focus of a powerful burning lens. Their experiment has been repeated by subsequent chemists, with various modifications. It has been found by Sir George Mackenzie that diamonds burn in atmospheric air, when exposed on a muffle, to the temperature of about 14° Wedgwood. In oxygen gas the diamond takes fire, when the focus of a powerful lens is thrown upon it; and continues to burn, though removed out of the focus, with a steady brilliant light, visible in the strongest sunshine. (Davy, in Phil. Trans. 1814.) The portion of diamond, which remains unconsumed, is not rendered black, as has been asserted, but is found to have lost its lustre, like glass acted on by fluoric acid. When the vessel has become cold, no production whatsoever of moisture is visible. By effecting its combustion in this way, Guyton thought he had determined that the diamond, in an equal weight, contains more real carbon than exists in common charcoal. His experiments, however, have not been confirmed by those of other chemists.

One fact, however, has been contributed on this subject by Guyton, which is of considerable value. The diamond, he first ascertained, is destroyed when thrown into red-hot and melted nitre; and this property, it will afterwards appear, has been successfully applied by Mr. Tennant to the determination of the nature of the diamond, and of the proportion of ingredients in carbonic acid.

At the Royal Institution, an apparatus is employed for the combustion of the diamond, from which, with Mr. Brande's permission, the annexed sketch has been taken. It consists of a glass globe, capable of holding about 140 cubical inches, which, when used, is first exhausted, and then filled with oxygen gas. In the centre of this globe is supported a small hemispherical cup of platinum, pierced with small holes. This is destined for containing the diamonds; and beneath it, at the distance of about [illegible] of an inch, is the orifice of a small pipe, from which a jet of hydrogen gas may be



forced, by opening the cock and pressing the bladder. This stream of hydrogen being lighted by electric sparks, taken by means of a contrivance usually employed for that purpose, ignites the diamonds, and, when they are white-hot, the gas is extinguished by shutting the cock. The diamonds continue to burn till they are so much reduced in size that the cooling power of the platinum, with which they are in contact, prevents their farther combustion. After the apparatus has cooled, the gas within the globe will be found, when examined by rules which will presently be given, to have undergone an essential change, and to be partly converted into carbonic acid.

To collect the entire products of the combustion of carbon, in either of its forms, requires rather a complicated apparatus. Lavoisier burnt charcoal in a known quantity of oxygen gas, which was confined by mercury, the charcoal being set on fire by a bent iron wire heated to redness, and introduced through the quicksilver. (Elements of Chemistry, pl. iv. fig. 3.) Messrs. Allen and Pepys collected the products of the combustion of charcoal and of the diamond, by burning them separately in a platinum tube, set horizontally in a charcoal furnace, and connected at each extremity with a mercurial gazometer. A correct idea of this arrangement will easily be obtained by imagining that to each end of the tube *c*, fig. 40, the pipe *b* of a gazometer, like that shown fig. 35, is connected. At the outset of the experiment, one of the gazometers was filled with a known quantity of the purest oxygen gas, and the other was empty. The tube was then made red-hot; and the gas, being forced alternately from one gazometer to the other, was repeatedly brought into contact with the red-hot charcoal or diamond. The volume of the gas was found to be entirely unaltered; but it had received an addition to its weight precisely equal to what the charcoal or diamond, on weighing, was ascertained to have lost; and it was partly converted into a gas, called carbonic acid, totally different in its properties from oxygen gas. It appears, therefore, that oxygen gas, by conversion into carbonic acid, undergoes neither expansion nor condensation. This conclusion is farther established by the recent experiments of Sir H. Davy, on the combustion of the diamond in oxygen gas.

Carbonic Acid.

From the quantity of charcoal or diamond consumed in the experiments of Allen and Pepys, and the quantity of oxygen converted into carbonic acid, it is easy to infer the proportion of carbon and oxygen in the new compound. Reducing these to centesimal proportion, for every 28 or 29 grains of the combustible base which disappeared, 100 grains of carbonic acid (= about 201 cubic inches) were generated; and it is remarkable that these proportions agree exactly with those originally stated by Lavoisier. The same quantity of carbonic acid resulted, also, from the combustion of between 28 and 29 grains of diamond. Hence it may be inferred, that the actual quantity of carbon in equal weights of diamond and charcoal is very nearly the same; and that charcoal is not, as has hitherto been supposed, an oxide of carbon; their only difference consisting in the presence of hydrogen in charcoal, in so small a proportion as not materially to diminish the quantity of carbonic acid produced by its combustion. If this inference required confirmation, it is furnished by its agreement with Mr. Tennant's experiments on the combustion of the diamond, published in 1797. Two grains and a half of diamond (that philosopher found), when consumed in a tube of gold by means of nitre, gave nine grains of carbonic acid, which, in 100 parts, should contain, therefore, as nearly as possible, 28 parts of diamond or carbon. The mean of a number of Messrs. Pepys and Allen's experiments give the following statement of the composition of carbonic acid:

Carbon	28.60	6
Oxygen	71.40	15 very nearly.
	100.	

It is remarkable, also, that these numbers precisely agree with those deduced from the experiments of Clement and Desormes. (Ann. de Chim. xxxix. 42.) They differ, however, a little from those of Saussure, jun., who states the carbon in 100 grains of carbonic acid at between 27.04 and 27.58 grains. The results of Gay Lussac, which are conformable with the views of Berzelius, and, as nearly as possible with those of Dr. Wollaston, are,

Carbon	27.376	6
Oxygen	72.624	16 very nearly.
	100.	

In experiments of such extreme delicacy, all that can be expected is a near approximation to the true proportions of the elements of compound gases, and we are in this case entitled to conclude that 6 by weight (one atom) of charcoal unites **with** 16 by weight (two atoms) of oxygen to form 22 of carbonic acid, the atom of which is correctly represented by the number 22. In volumes, its constitution has been stated by Gay Lussac to be 1 of gaseous carbon + 1 of oxygen, condensed into the space of 1 volume, and the density of the vapour of charcoal to be equal to the density of carbonic acid, less that of oxygen gas, or to 1.5277 — 1.1111 = 0.4166. When to 1 volume of carbonic oxide, a compound (presently to be described) of 6 by weight, or 1 atom, of carbon, and 8, = 1 atom, of oxygen, we add half a volume of oxygen, and detonate the mixture over mercury, we obtain one volume of carbonic acid, which gas may therefore be considered as constituted either of one volume of carbonic oxide + half a vol. of oxygen condensed into one volume, or of one volume of vaporous carbon + 1 vol. of oxygen, condensed into 1 volume.

In addition to the proofs of the constitution of carbonic acid, derived from its synthesis, we have also the evidence of its analysis, which may be effected by several processes.

1. By passing a succession of electrical discharges through a quantity of carbonic acid gas confined over mercury, I have found that the gas is separated into oxygen, and carbonic oxide. When the carbonic acid, which escapes decomposition, has been washed out by solution of potassa, an electric spark inflames the residuary mixture; the oxygen and carbonic oxide again uniting, and recomposing carbonic acid. (Phil. Trans. 1809, p, 448.)

2. When a mixture of carbonic acid and hydrogen gases is electrified, the hydrogen combines with part of the oxygen of the acid, and reduces it to the state of carbonic oxide. The same products are obtained, by transmitting a mixture of two parts of hydrogen gas and one of carbonic acid through a glazed porcelain tube strongly ignited. The hydrogen uniting with a part of the oxygen of the carbonic acid, brings the latter to the state of carbonic oxide, at the same time that water is formed.

3. When potassium is heated in carbonic acid gas, Sir H. Davy has found that the metal inflames; part of it is oxidated at the expense of the acid; and part of it unites with the charcoal, which is precipitated.

4. By simply heating phosphorus in carbonic acid gas, no step is made towards the decomposition of the latter. But, by applying phosphorus to some of the combinations of carbonic acid, the phosphorus is oxygenated, and carbon appears in a separate form. The original discovery of this fact is due to the late Mr. Smithson Tennant (Phil. Trans. 1791, p. 182); and the details of the experiment have been minutely followed up by Dr. Pearson. (Phil. Trans. 1792, p. 289.)

To exhibit this fact, provide a tube of very thin glass, about one-third of an inch wide, and eighteen or twenty inches long, sealed at one end. Coat it, within about an inch of the sealed extremity, with a lute of sand and clay; and, when this is dry, put into it as much purified phosphorus, in small pieces, as will fill the uncoated part. Then cover the phosphorus with fragments of carbonate of lime, or carbonate of soda which has been deprived of its water of crystallization. Let the part of the tube, which contains the carbonate, be made red-hot by means of a portable furnace; and, at this moment, apply heat to the part containing the phosphorus, sufficient to melt and raise it into vapour. The vapour of the phosphorus, coming into contact with the red-hot carbonate, will decompose the carbonic acid; and charcoal will be found in the residue of the process, in the form of a very light and black powder.

To procure carbonic acid, sufficiently pure for the exhibition of its properties, the combustion of charcoal is far from the best process. The student may, therefore, have recourse to another, the *rationale* of which he will not, at present, understand; but which will be explained afterwards. Into a common gas bottle put a little powdered marble or chalk, and pour on this sulphuric acid, diluted with five or six times its weight of water; or upon small fragments of marble about the size of horse-beans, contained in a gas bottle, pour muriatic acid diluted with eight or ten times its weight of water, which disengages the gas more slowly and conveniently. This gas may be received over mercury; but a mercurial apparatus is not absolutely essential, since the gas may be collected over water, if used immediately when procured. Carbonic acid may also be separated by heat alone from carbonate of lime. For this purpose, coarsely powdered chalk or marble may be put into the iron vessel *a*, fig. 85, which may be connected, by means of the conducting pipe *b*, with a gazometer. The receiving cylinder of the latter, after a sufficiently long continuance of heat to the bottle *a*, will be filled with carbonic acid gas; contaminated, however, by a small proportion of carbonic oxide, and sometimes a little hydrogen.

Liquefaction of Carbonic Acid.

Carbonic acid was liquefied by Mr. Faraday in the following manner. Into a tube, bent and sealed at the shorter end, strong sulphuric acid was poured through a small funnel, so as nearly to fill the short leg without soiling the longer one. A piece of platinum foil was then crumpled up and pushed in, and upon that were put fragments of carbonate of ammonia until the tube was nearly full. In this way action was prevented, until the tube was sealed. When closed, the sulphuric acid was made to run upon the ammoniacal carbonate, and the clean end of the tube was immersed in a freezing mixture. Much stronger tubes are required in this case than in any similar one; and the danger of violent explosions, from variations in the temperature of the atmosphere, renders great caution necessary in handling them.

Carbonic acid thus produced is limpid, colourless, extremely fluid, and floats upon the other substances in the tube. It distils readily and rapidly at the difference of temper[illegible]e between 32° and 0°. Its refractive power is much less than that of water. Its appearance was unaltered by any diminution of temperature to which it was subjected. In endeavouring to open the tubes at one end, they uniformly burst into fragments with powerful explosions. By enclosing a gauge in a tube, in which fluid carbonic acid was afterwards produced, it was found that its vapour exerted, at 32° Fahr., a pressure of 36 atmospheres.

Properties of carbonic acid gas.—Aëriform carbonic acid has the following properties:

It extinguishes flame.—Set a vessel, filled with gas, with its mouth upwards, and let down a lighted candle. The candle will instantly be extinguished. A person, says Dr. Priestley, who is quite a stranger to the properties of this kind of gas, will be agreeably amused with extinguishing lighted candles, or blazing chips of wood, on its surface. For the smoke readily unites with this kind of air; so that little or none of it escapes into the atmosphere. It is remarkable, that the upper surface of this smoke, floating in the fixed air, is smooth and well defined; whereas the lower surface is exceedingly ragged, several parts hanging down to a considerable distance within the body of the carbonic acid, and sometimes in the form of balls, connected to the upper stratum by slender threads, as if they were suspended. The smoke is also apt to form itself into broad flakes, exactly like clouds. Making an agitation in this air, the surface of it (which still continues exactly defined) is thrown into the form of waves; and if, by this agitation, any of the carbonic acid be thrown over the sides of the vessel, the smoke which is mixed with it will fall to the ground, as if it were so much water.

It is fatal to animals.—Put a mouse, or other small animal, into a vessel of the gas, and cover the vessel, to prevent the contact of common air. The animal will die in the course of a minute or two. In this way, butterflies, and other insects, the colours of which it is desirable to preserve, for the purpose of cabinet specimens, may be suffocated better than by the common mode of killing them with the fumes of sulphur.

Specific gravity.—According to Sir H. Davy, 100 cubic inches, at 55° Fahrenheit, and 30 inches of the barometer, weigh 47.5 grains; and at 60°, with the same pressure, would weigh 47.11. Messrs. Allen and Pepys determined that 100 cubic inches, at 60° Fahr., and 30 inches barometer, weigh 47.26 grains. Its specific gravity, according to Biot and Arago, is 1.5196; and hence, if 100 cubic inches of atmospheric air weigh 30.5 grains, the same bulk of carbonic acid gas should weigh 46.34 grains. Dr. Ure finds 100 cubic inches to weigh 46.4 grains. Dr. Thomson states its specific gravity to be 1.52778, and Berzelius and Dulong 1.5240. It will be a sufficiently near approximation to take the weight of 100 cubical inches at 46.55 grains, at a mean of the barometer and thermometer.

To show the superior specific gravity of this gas in a general way, the following experiment will be sufficient. Let a long glass tube, proceeding from a gas bottle, containing powdered marble and dilute sulphuric acid, be twice bent at right angles; let the open end of the longer leg reach the bottom of a glass jar, perfectly dry within, and standing with its mouth uppermost. The carbonic acid will expel the common air from the jar, because it is heavier. This superior gravity may be farther shown as follows: When the jar is perfectly filled with the gas (which may be known by a lighted candle being instantly extinguished when let down into it), take another jar, of rather smaller size, and place at the bottom of it a lighted taper, supported by a stand: then pour the contents of the first-mentioned jar into the second, as if you were pouring water. The candle will be instantly extinguished, as effectually as if it had been immersed in water.

It is owing to its superior gravity that carbonic acid gas is often found at the bottom of grottoes, of deep wells, and of mines, the upper part of which is entirely free from it. Hence the precaution, used by the sinkers of wells, of letting down a candle before they venture to descend in person.

Absorption by water.—Fill partly a jar with this gas, and let it stand inverted a few hours over water. An absorption will gradually go on, till at last none will remain. This absorption is infinitely quicker when agitation is used. Repeat the above experiment, with this difference, that the jar must be shaken strongly. A very rapid diminution will now take place. In this manner water may be charged, under common atmospheric pressure, with rather more than its own bulk of carbonic acid gas; and acquires, when thus saturated, a very brisk and pleasant taste. This impregnation is most commodiously effected on a small scale, by an apparatus, sold in the glass shops, under the name of Nooth's machine.

The influence of increased pressure, in causing water to absorb a large quantity of carbonic acid, may be illustrated by an apparatus, which I have described in the Philosophical Transactions for 1803, but which cannot be understood without the engraving that accompanies it. From an extensive series of experiments with this apparatus, I have deduced, as a general law, *that water takes up the same volume of compressed carbonic acid gas, as of gas under ordinary pressure.* And since the space occupied by any gas is inversely as the compressing force, it follows *that the quantity of gas, forced into water, is directly as the pressure.* Thus, if water under common circumstances takes up an equal bulk of carbonic acid, under the pressure of two atmospheres it will absorb twice its bulk; under three atmospheres three times its bulk, and so on.

From water, thus impregnated, carbonic acid is again set at liberty on boiling the water, or by exposing it under the receiver of an air-pump. During exhaustion, the gas will escape so rapidly, as to present the appearance of ebullition; and will be much more remarkable than the discharge of air from a jarful of common spring water, confined at the same time under the receiver, as a standard of comparison. The gas slowly, but almost entirely, escapes from water which, after being impregnated with it, is exposed with a broad surface to the atmosphere. If the impregnated water be rapidly congealed, by surrounding it with a mixture of snow and salt, the frozen water has more the appearance of snow than of ice, its bulk being prodigiously increased by the disengagement of an immense number of air-bubbles. When water, thus congealed, is liquefied again, it is found, by its taste and other properties, to have lost nearly the whole of its carbonic acid.

Acidity of the gas.—This may be shown by dipping into water, impregnated with it, a bit of litmus paper, or by mixing with a portion of the liquid about an equal bulk of the infusion of litmus. This fact establishes the title of the gas to be ranked among acids. When an infusion of litmus, which has been thus reddened, is either heated or exposed to the air, its blue colour is restored, in consequence of the escape of the carbonic acid. This is a marked ground of distinction from most other acids, the effect of which is permanent, even after boiling.

Action of the gas on lime water.—Pass the gas, as it proceeds from the materials, through a portion of lime water; this, though perfectly transparent before, will instantly grow milky. Or, mix equal measures of water saturated with carbonic acid and lime water; the same precipitation will ensue. By means of lime water, the whole of any quantity of carbonic acid existing in a mixture of gases cannot, however, be removed, as Saussure, jun. has shown; but recourse must be had, in order to effect its entire absorption, to a solution of caustic potassa or soda.

The precipitation of lime water is the best test of the formation of carbonic acid in several cases of combustion. 1. Let the chimney of a small portable furnace, in which charcoal is burning, terminate, at a distance sufficiently remote to allow of its being kept cool, in the bottom of a barrel provided with a moveable top, or of a large glass vessel having two openings. A small jar of lime water being let down into the tub or vessel, and agitated, the lime water will immediately become milky. The gas will also extinguish burning bodies, and prove fatal to animals that are confined in it. Hence the danger of exposure to the fumes of charcoal, which, in several instances, have been known to be fatal: these fumes consist of a mixture of carbonic acid and nitrogen gases, with a very small proportion of oxygen gas. 2. Fill the pneumato-chemical trough with lime water, and burn a candle, in a jar filled with atmospheric air, over the lime water, till the flame is extinguished. On agitating the jar the lime water will become milky. The same appearances will take place, more speedily and remarkably, if oxygen gas be substituted for common air. The carbonic acid, thus formed during combustion, by its admixture with the residuary air, renders it more unfit for supporting flame than it otherwise would be from the mere loss of oxygen. Hence, if a candle be burnt in oxygen gas, it is extinguished long before the oxygen is totally absorbed, because the admixture of carbonic acid with oxygen gas, in considerable proportion, unfits it for supporting combustion. Whenever any substance, by combustion in oxygen gas or common air over lime water, gives a precipitate, soluble with effervescence in muriatic acid, we may confidently infer that it contains carbon.

The production of carbonic acid, by respiration, may be exhibited, also, by blowing the air from the lungs, with the aid of a quill, through lime water, which will immediately grow milky. The carbonic acid, thus added to a confined portion of air, unfits it for supporting life, not merely by diminishing the proportion of oxygen gas, but apparently by exerting a positively noxious effect. Hence a given quantity of air will support an animal much longer, when the carbonic acid is removed as fast as it is formed, than when suffered to remain in a state of mixture. It has been found that an atmosphere, consisting of oxygen gas and carbonic acid, is fatal to animals, though it should contain a larger proportion of oxygen than the air we commonly breathe.

Carbonic acid is a constant ingredient of atmospheric air.—Its presence is demonstrated by leaving a shallow vessel of lime water exposed to the atmosphere; for its surface is soon covered with a solid pellicle, which, when removed, is succeeded by another, and so on, till the water is deprived of almost all the lime which it held in solution. From the precipitate, thus formed, carbonic acid is disengaged by dilute acids. It has been discovered not only in air at ordinary heights, but was ascertained by Saussure to exist in the atmosphere on the summit of Mont Blanc, nearly 16,000 feet above the level of the sea, and was found by Humboldt in air brought down by Garnerin from the height of several thousand feet, to which he had ascended in an air balloon. (Jour. de Phys. xlvii. 202.) In air, however, taken at sea, at the distance of two leagues from Dieppe, Vogel found so little carbonic acid, that it scarcely affected the transparency of the watery solution of baryta, though, when the experiment was repeated on shore, the same solution became extremely turbid. (Ann. of Phil. N. S. vi. 75.)

The proportion of carbonic acid in atmospheric air is estimated by Mr. Dalton not to exceed $\frac{3}{1000}$ or $\frac{1}{1400}$ of its bulk. Saussure, jun. examined its proportion in the air of an open field, a few miles from Geneva. (Ann. de Chim. et Phys. ii. 19, iii. 170, and xxxviii. 412.) In January, the mean of three experiments showed 4.79 parts in 10,000; in July and August, 7.18 parts in the same volume, which is considerably short of the proportion determined by Mr. Dalton. The difference between the quantities discovered in summer and winter, though on first view very small, *viz.* $2\frac{1}{10}$ volumes in ten thousand, would constitute so large a quantity, when the whole atmosphere is taken into the account, that the fact can scarcely be considered as determined without repeated and careful experiments. Recently, however, Saussure has again made experiments on this subject. He finds the mean proportion of carbonic acid in the air of a valley, about three-fourths of a league from Geneva, to be 4.9 parts in 10.000. It is greater in the three winter, than in the three summer months, in the proportion of 100 to 77. The proportion in August, taken on a mean of several years, is 5.68; but, in a cold wet season, observation in the middle of the day gave only 4.45. It is a little less in air over the surface of the lake, and in the town of Geneva exceeded that found in air from the country. No differences, Saussure adds, have as yet been discovered by him in the proportion of atmospheric oxygen. (Ann. de Ch. et Phys. Aug. 1828.)

Carbonic acid retards the putrefaction of animal substances.—This may be proved by suspending two equal pieces of flesh meat, the one in common air, the other in carbonic acid gas, or in a small vessel through which a stream of carbonic acid is constantly passing. The latter will be preserved untainted, some time after the other has begun to putrefy.

Carbonic acid gas exerts powerful effects on living vegetables.—These effects, however, vary according to the mode of its application. Water, saturated with this gas, proves highly nutritious to plants, when applied to their roots. The carbonic acid is decomposed, its carbon forming a component part of the vegetable, and its oxygen being liberated in a gaseous form. On the contrary, carbonic acid, when a living vegetable is confined in the undiluted gas over water, is injurious to the health of the plant, especially in the shade. The late Mr. Henry, however, long ago, found that a certain quantity of fixed air, applied as an atmosphere, is favourable to vegetation; and M. Saussure, of Geneva, has determined, more recently, that the mixture of more than $\frac{1}{8}$ of carbonic acid with common air is always injurious, but that, in this proportion, it promotes the growth of plants, and is manifestly decomposed. It is this process of nature that appears to be the principal means of preventing an excess of carbonic acid in the general mass of the atmosphere, which, without some provision of this kind, must gradually, in the course of ages, be rendered less and less fit for respiration.

Gaseous Oxide of Carbon, or Carbonic Oxide.

This gas appears to have been first obtained by Dr. Priestley, by the distillation of charcoal with oxide of zinc; but he was not aware of its composition, which was first pointed out by the late Mr. Cruickshank, of Woolwich, (Nicholson's Journal, 4to. vol. 5,) and afterwards more particularly by Clément and Desormes. (Ann. de Ch. xxxix. 26.) The Dutch Society of Chemists objected to its being regarded as a distinct species, and considered it only as a variety of carbureted hydrogen, (2 Ann. de Ch. xliii.) But these objections were not entitled to any weight, and have been completely set aside by subsequent investigations.

It may be procured by any of the following processes:

1. By the distillation of the white oxide of zinc with one eighth of its weight of charcoal, in an earthen or glass retort; from the scales which fly from iron in forging, mixed with a similar proportion of charcoal; from the oxides of lead, manganese, or, indeed, of almost every imperfect metal, when heated in contact with powdered charcoal. It may also be obtained from the substance which remains after preparing acetic acid from bin-acetate of copper.

2. From well dried carbonate of baryta or of lime (common chalk), distilled with about one-fifth of charcoal, or with rather a larger proportion of dry iron or zinc filings, which afford it quite free from hydrogen.

3. By transmitting carbonic acid gas over charcoal ignited in a porcelain tube, the acid gas combines with an additional dose of charcoal; loses its acid properties; and is converted into a double volume of carbonic oxide. An ingenious apparatus, contrived by M. Baruel, and extremely useful for this and similar purposes, is described and represented by a plate, in the 11th volume of Nicholson's Journal.

4. A process has been proposed by Dumas, (Ann. de Ch. et de Phys. xxxiii. 110,) which I find very convenient for the extemporaneous formation of this gas. It consists in mixing salt of sorrel with five or six times its weight of concentrated sulphuric acid, and heating the mixture in a gas bottle. The evolved gas, after

removing the carbonic acid by liquid potassa, is pure carbonic oxide. This washing with potassa is, indeed, necessary, from whatever source the gas may have been obtained.

The properties of carbonic oxide gas are as follow:

It has an offensive smell. It is lighter than common air in the proportion of 0.9722 according to Thomson, or 0.9727 according to Berzelius and Dulong. One hundred cubical inches weigh 30 grains, the temperature being 55° Fahrenheit, and pressure 29.5 (Cruickshank); or at temperature 60°, and barometer 30, 100 cubic inches weigh 30.19 grains.

It is inflammable, and, when set fire to, as it issues from the orifice of a small pipe, burns with a feeble blue flame. The temperature of an iron wire, heated to dull redness, was found by Sir H. Davy sufficient to kindle it. When mixed with common air, it does not explode like other inflammable gases, unless in very few proportions, but burns silently with a lambent blue flame. (Dalton's System, p. 373.) A mixture of two measures with one measure of common air may, however, be exploded by a lighted taper, or even by red-hot iron or charcoal.

When a mixture of carbonic oxide with more than half its volume of oxygen gas is exposed over mercury, in contact with spongy platinum, to a temperature between 300° and 310° Fahr., it begins to be converted into carbonic acid, and at a heat a few degrees higher, is wholly acidified in the course of a few minutes. Mixtures of these two gases are, however, very slowly acted upon by the platinum sponge at common temperatures.

When carbonic oxide is added, in an equal volume, to a mixture of hydrogen and oxygen gases in explosive proportions, it prevents spongy platinum from causing detonation, but the agency of the gases on each other goes on slowly, and both water and carbonic acid are formed. Into a mixture of carbonic oxide, with a larger proportion of the explosive mixture, the platinum sponge cannot be introduced without causing detonation. (Phil. Trans. 1824, p. 271.)

When a stream of well dried carbonic oxide is burnt, in the manner described in speaking of hydrogen gas, no water is condensed on the inner surface of the glass globe, a proof that the gaseous oxide contains no hydrogen.

It is sparingly absorbed by water; is not absorbed by liquid caustic alkalies; nor does it precipitate lime water.

It is extremely noxious to animals; and fatal to them if confined in it. When respired for a few minutes, it produces giddiness and fainting. (Phil. Mag. xliii. 367.)

When 100 measures of carbonic oxide are fired over mercury in a detonating tube, with 50 of oxygen gas, the total 150 are diminished to 100, which, if the gases employed be pure, consist entirely of carbonic acid.

It is not expanded by electric shocks, nor does it undergo any change by electrization, however long continued.

When carbonic oxide, mingled with an equal bulk of hydrogen gas, is passed through an ignited tube, the tube becomes lined with charcoal. In this temperature, the hydrogen attracts oxygen more strongly than it is retained by the charcoal, and water is formed. It was found, also, by Gay Lussac, to be decomposed by the action of potassium, which combines with the oxygen, and precipitates charcoal; and Döbereiner, by bringing it into contact with sulphureted oxide of platinum, converted it into half its volume of carbonic acid.

Composition.—Gay Lussac deduced carbonic oxide to consist of 43 charcoal and 57 oxygen; Berzelius of 44.28 charcoal and 55.72 oxygen, proportions which agree, within a small fraction, with those of Clément and Desormes. There cannot now be any doubt that it is composed of 6 by weight (= 1 atom) of carbon + 8 (= 1 atom) of oxygen. It contains, therefore, just half the oxygen present in carbonic acid. It may be viewed as constituted of half a volume of oxygen and 1 volume of gaseous carbon, condensed into 1 volume. Its specific gravity should, therefore, be found by adding half the sp. gr. of oxygen to the sp. gr. of gaseous carbon, viz. $0.4166 + 0.5555 = 0.9722$.

ART. 2.—*Carbon with Chlorine.*

Several attempts have been made to effect the combination of chlorine with carbon, by igniting charcoal in chlorine gas; but, though unsuccessful, there appeared to be no reason for inferring a want of affinity between those two elements, which it seemed reasonable to conclude from other phenomena, might be rendered efficient, by bringing the two bodies into contact, in a state favourable to their union. The most probable method seemed to be to employ some compound, in which carbon exists in a minute state of division, and yet not of such intimate combination, as to preclude its union with chlorine. Mr. Faraday, therefore, to whom we are indebted for a masterly set of experiments on this subject, which ended in his effecting the object in view, employed a compound of charcoal and hydrogen, which will be hereafter described under the name of olefiant gas, as best adapted to the purpose. At present it is only necessary to observe, that olefiant gas is a compound of 1 atom of carbon with 1 atom of hydrogen; that when mixed with an equal volume of chlorine, the three elements all unite, and form a liquid ternary compound of chlorine, carbon, and hydrogen; and that, by subjecting this triple compound to the repeated action of fresh quantities of chlorine, the hydrogen may be entirely abstracted, and a compound of chlorine and carbon produced.

To prepare this substance, a retort or other glass vessel of the capacity of about 200 cubic inches, provided with a brass cap and stop-cock, is first to be exhausted by the air pump, and then made to communicate with a jar filled with chlorine. It is next to be screwed on a vessel full of olefiant gas, and as much as can find admission having entered, the cock is to be shut, and the whole left for a short time. When the fluid, composed of chlorine and olefiant gases, has formed and condensed on the sides of the vessel, the vessel is again to be placed over olefiant gas, and a further portion admitted. This process is to be repeated, till all the chlorine has united to form the fluid, and the vessel remains full of olefiant gas. Chlorine is then to be admitted by repeated portions, in consequence of which more of the fluid is formed, and ultimately a large portion is obtained, with an atmosphere of chlorine above it. The vessel is now to be exposed to the sun's rays, which cause the immediate formation of muriatic acid gas. This may be absorbed by admitting a small portion of water; and then another atmosphere of chlorine is to be introduced. Again exposed to the light, this will partly combine with the carbon, and partly form muriatic acid gas, which being, as before, absorbed by water, leaves space for more chlorine. Repeating this action, the fluid gradually becomes thick and opaque, from the formation of crystals in it, which at last adhere to the sides of the vessel as it is turned round; and ultimately the vessel contains only chlorine, with the accumulated impurities of the gases; a strong solution of muriatic acid coloured blue by its action on the brass; and the solid substance in question.

In order to cleanse the substance, the remaining gases are first to be blown out of the vessel by a pair of bellows, and the vessel is then to be filled with water to wash away the muriatic acid and other soluble matters. The new substance is then to be detached from the inside of the vessel, and poured with the water into a jar. A little alcohol will remove the last portions which adhere to the glass, and, when poured into the water, will precipitate the new compound, which must be collected on a filter, and dried as much as possible by pressure between folds of bibulous paper. It must next be introduced into a glass tube, and sublimed by a spirit lamp. A part will be decomposed, but the sublimed portion is to be dissolved in alcohol, and poured into a weak solution of potassa, by which the new substance is thrown down, and the muriatic acid neutralized and separated. Then wash away the potassa and muriate by repeated affusions of water, until the substance remains pure; collect it on a filter, and dry it, first by pressure between folds of unsized paper, and afterwards by sulphuric acid under the exhausted receiver of an air pump. It will now appear as a white pulverulent substance; and, if perfectly pure, will not, when a little is sublimed in a tube, leave the slightest trace of carbon, or afford any muriatic acid. A small portion dissolved in ether should give no precipitate with nitrate of silver. If not quite pure, it must be re-sublimed, washed, and dried, as often as is necessary.

To this compound Mr. Faraday has given the name of *perchloride of carbon.* When pure, it is, immediately after fusion, a transparent colourless substance, having scarcely any taste. Its odour is aromatic, and approaches that of camphor. Its specific gravity is as nearly as possible [illegible]. Its refractive power is high, being above that of flint glass 1.5767. It is very friable, easily breaking down on pressure, and, when scratched, has much of the feel and appearance of white sugar. It does not conduct electricity. It is crystallizable, and the varieties of its form result from a right rhombic prism. (Brooke in Ann. of Phil. N. S. vii. 364.

It volatilizes slowly at common temperatures, and, like camphor, passes towards the light. At 320° Fahr. it fuses, and boils at 360°. When condensed from these rapid sublimations, it is in so transparent and colourless a state, that it is difficult to perceive where it is lodged.

It is not readily combustible. When held in the flame of a spirit lamp, it burns with a red flame, emitting much smoke and acid fumes; but, when removed from the lamp, combustion ceases. In an atmosphere of pure oxygen, it burns with a brilliant light.

It is very sparingly soluble in water, either hot or cold, but dissolves readily in alcohol, especially if heated. The solution is decomposed when poured into water, and gives regular crystals on cooling or evaporation, but does not, with nitrate of silver, form the chloride of that metal. Ether, particularly when heated, dissolves it even more readily than alcohol. It is soluble also in volatile oils, and in fixed oils, but the latter solutions assume a charred appearance when heated.

It is not changed by solutions of pure alkalies, even when applied boiling hot; nor is it attacked by concentrated and heated muriatic, nitric, or sulphuric acids.

When transmitted in vapour mixed with oxygen gas through a red-hot tube, there is a decomposition; and mixtures of chlorine, carbonic acid, carbonic oxide, and chloro-carbonic acid, are evolved. It is decomposed also by per-oxide of mercury, with the aid of heat.

Chlorine has no action on it. Iodine either unites with it, or at high temperatures takes away a portion of chlorine. Hydrogen gas, when transmitted along with it through red-hot tubes, decomposes it, and muriatic acid and charcoal are produced.

Sulphur, at moderate temperatures, unites with it; at higher ones, removes one portion of chlorine. The same effect is produced by phosphorus. Charcoal is quite inefficient on it. Most of the metals decompose it with the aid of heat, forming chlorides, and charcoal being liberated. Per-oxides produce with it, at a high temperature, chlorides and carbonic acid; protoxides afford chlorides and carbonic oxide.

In forming this substance, Mr. Faraday believes that five volumes of chlorine gas saturate one of olefiant, and produce four volumes of muriatic acid gas; that three volumes of the chlorine combine with the two volumes of charcoal existing in the olefiant gas to form the crystalline solid; and that when chlorine acts on the fluid compound of chlorine and olefiant gas, for every volume of chlorine that combines, an equal volume of hydrogen is separated. The results of its analysis by per-oxide of copper confirm these views, and tend to establish that the composition of per-chloride is

3 atoms of chlorine - - - - - = 108
2 do. of carbon - - - - - = 12

Weight of its atom 120

Proto-chloride of Carbon.

By passing the vapour of per-chloride of carbon over fragments of rock crystal ignited in a glass tube, the upper part of which is bent up and down two or three times, so that the angles may form receivers for the new compound, a partial decomposition is effected; one portion of chlorine is separated, and escapes; and the remainder, continuing united to the carbon, forms a fluid substance, which may be collected and purified by repeated distillations. This is the *proto-chloride of carbon.*

It is a highly limpid and perfectly colourless fluid; its specific gravity is 1.5526; it is a non-conductor of electricity; its refractive power is 1.4875, being very nearly that of camphor. It is not combustible, except when held in the flame of a spirit lamp, and then it burns with a bright yellow light, much smoke, and fumes of muriatic acid.

It does not become solid at 0° Fahr. When its temperature is raised under the surface of water to between 160° and 170°, it is converted into vapour, and remains in that state, till the temperature is lowered. When its vapour is passed over ignited fragments of rock crystal, it undergoes a partial decomposition.

It is not miscible with water, but is soluble in alcohol, ether, and fixed and volatile oils. Neither alkaline solutions nor strong acids produce any effect upon it. It is not decomposed by solutions of silver. Oxygen gas, at high temperatures, forms with it carbonic oxide, and chlorine is liberated. Hydrogen, under the same circumstances, forms muriatic acid with its chlorine, and charcoal appears. The metals, at high degrees of heat, absorb the chlorine, and liberate charcoal; oxides, according to their proportion of oxygen, form with it either carbonic acid or carbonic oxide.

By analysis, effected by per-oxide of copper, it is shown to be constituted of

1 atom of chlorine - - - - - -	36
1 do. of carbon - - - - - -	6
Weight of its atom	42

Sub-chloride of Carbon.

A third compound of chlorine and carbon was brought over from Sweden by M. Julin of Abo, where it had been accidentally formed during the distillation of nitric acid from crude nitre and sulphate of iron. The quantity produced at each process did not exceed a few grains, which condensed in fine white feathery crystals in a glass tube connecting the first and second receiver. Its properties are described by M. Julin as follows: (Ann of Phil. N. S. i. 216.)

It is white; consists of small soft adhesive fibres; sinks slowly in water; is insoluble in it whether hot or cold; is tasteless; has a peculiar smell, somewhat resembling spermaceti; is not acted upon by concentrated and boiling acids or alkalies, except that some of them dissolve a small portion of sulphur; dissolves in hot oil of turpentine, and in alcohol, but most of it crystallizes in needles on cooling; burns in the flame of a lamp with a greenish blue flame, and a slight smell of chlorine; when heated melts, boils, and sublimes between 350° and 450° Fahr., or sublimes slowly at a heat of 250°, forming long needles. Potassium burns with a vivid flame in its vapour, and charcoal is deposited; and a solution of the residuum in nitric acid gives a copious precipitate with nitrate of silver.

A small quantity of this substance, having been put into the hands of Messrs. R. Phillips and Faraday, has been made by them the subject of analysis. They found that it might readily be purified from sulphur by boiling in liquid potassa, washing in water, drying, and subliming, when it formed beautiful acicular crystals, in the form of four-sided prisms.

It was decomposed into chlorine and charcoal by being passed over red-hot fragments of rock crystal. Its vapour being detonated over mercury with excess of oxygen, gave carbonic acid gas and chloride of mercury. When heated with phosphorus, iron, or tin, chlorides of those substances were formed, and charcoal deposited. Its analysis was effected in two ways; by being transmitted over ignited per-oxide of copper, and over dry quicklime. Both processes gave results which conspired to show that it is constituted of

1 atom of chlorine - - - - -	36
2 atoms of carbon - - - - -	12
Weight of its atom - -	48

Messrs. Phillips and Faraday have not given any name to this compound. It may be called, provisionally, the sub-chloride of carbon.

Thus we have three distinct compounds of chlorine and carbon, *viz.*

	At. of Chlor.		At. of Carb.
The per-chloride - -	3	+	2
The proto-chloride -	1	+	1
The sub-chloride - -	1	+	2

It is probable that another chloride of carbon will hereafter be found, consisting of two atoms of chlorine and one of carbon.

ART. 3.—*Carbon with Chlorine and Oxygen.—Chloro-Carbonic Acid.*

When equal volumes of chlorine and carbonic oxide gases, both previously dried by fused chloride of calcium, are introduced into a flask which has been exhausted of air, and are then exposed for a quarter of an hour to bright sunshine, combination takes place, the colour of the chlorine disappears, and the gases are condensed into half their united volumes. Hence the specific gravity of the new gas must be equal to the specific gravity of chlorine (2.5) + that of carbonic oxide (0.9722) = 3.4722, and 100 cubic inches must weigh 105.9 grains. Being produced by the agency of light, it was called by Dr. Davy *phosgene gas*, but as it exhibits distinctly acid properties, it has since been better termed *chloro-carbonic acid*. It is constituted of an atom of carbon, an atom of oxygen, and an atom of chlorine, or of an atom of carbonic oxide and an atom of chlorine. Its equivalent, therefore, is 14 + 36 = 50.

Chloro-carbonic acid has an intolerably pungent odour, and excites a copious flow of tears. It reddens litmus paper. By contact with water, it is changed into muriatic and carbonic acid gases. It condenses four times its volume of ammoniacal gas, and the product is a white neutral salt, from which the more powerful acids disengage muriatic and carbonic acids, but acetic acid dissolves it without effervescence. Several of the metals decompose it, and unite with the chlorine, evolving carbonic oxide equivalent in volume to the original gas.

Chloro-carbonic gas affords then an example of an acid with a simple base, and two acidifying principles, oxygen and chlorine, which are not often united in the performance of this function.

Art. 4.—*Carbon with Iodine.*

The mixture of alcoholic solutions of iodine and of pure soda, which, according to Serullas, affords iodate of soda, iodide of sodium, and hydriodide of carbon, was found by Mitscherlich to give rise to a true combination of iodine and carbon. At the moment of admixture, the iodine unites with the sodium, and the oxygen becoming free, unites with the hydrogen of the alcohol and forms water, while the carbon of the alcohol (a fluid which consists of water + olefiant gas) composes, with another portion of iodine, iodide of carbon. Of this compound there are two varieties, which Mitscherlich has promised to describe more fully hereafter. (Ann. de Ch. et de Ph. xxxvii. 85.)

SECTION IV.

Boron.

Boron was first obtained by Sir H. Davy in 1808 by the action of Voltaic electricity on boracic acid. When that acid, slightly moistened with water, was exposed between two surfaces of platinum to a battery of 500 pairs of plates, an olive brown matter began immediately to appear on the negative surface, and gradually increased in quantity. This substance was found not to be acted on by water, but to dissolve with effervescence in warm nitric acid. When heated to redness on platinum, it burned slowly, and boracic acid was regenerated. Hence the name of *boron* has been applied to it.

The same substance was afterwards obtained more abundantly by Gay Lussac and Thenard, by the action of potassium. Equal parts of potassium and very pure vitreous boracic acid are put into a copper tube, which is gradually heated to redness. At the temperature of 302° Fahr. the mixture becomes suddenly red, and the potassium disappears by acting on the boracic acid. By washing the residuum with warm water, a greenish brown or olive substance is obtained, very friable, free from taste or smell, and of greater specific gravity than water. This is the base or radical of boracic acid. According to Berzelius, boron is obtained at the least expense of potassium, by heating that metal with fluoborate of potassa. (Quart. Journ. xviii. 396.) Doebereiner has procured it, though contaminated with much carbonaceous matter, by heating fused borate of soda, powdered and mixed with lamp-black, during two hours, at an intense heat.

Boron is insoluble in water, and does not change vegetable blue colours. Mixed with chlorate or nitrate of potassa, and projected into a red-hot crucible, it burns vividly, and boracic acid is reproduced. In close vessels it may be exposed to a strong heat, without undergoing any change except an increase of density, for it now sinks in sulphuric acid of sp. gr. 1.844. It is a non-conductor of electricity. The density of its vapour is calculated by Dumas to be 0.7487. (33 Ann. de Chim. et Ph. 391.)

When heated to 600° Fahr. in the open air, it burns vividly, absorbs oxygen, and affords boracic acid; but the coating, which it acquires of that acid, soon stops the combustion. The quantity of oxygen absorbed by a given weight of boron has been investigated by Gay Lussac and Thenard, and by Sir H. Davy; but their results differ widely from each other, the former making the oxygen only one-third the weight of the boron; and the latter, on a mean of two experiments, (the one by the combustion of boron in oxygen, the other by the action of potassium on boracic acid,) having determined that one of boron unites with more than two of oxygen. Berzelius, from the combustion of boron, deduces the composition of boracic acid to be one of boron by weight to two of oxygen. From a review of the experiments of others, and from his own researches into some of the compounds of boracic acid, Dr. Thomson adopts the same proportions of 1 boron to 2 oxygen. Admitting, then, as seems probable, that one atom of boron unites with two of oxygen to form boracic acid, boron will be represented by 8, and boracic acid by $8 + 16 = 24$. But we are to consider the atomic weight of this element as less satisfactorily determined than that of most others.

Boron with Oxygen.—Boracic Acid.

I. This acid is very rarely to be found native. It has hitherto been discovered only in the Lipari islands, and in the hot springs of Sasso in the Florentine territory. For purposes of experiment, it is obtained from the purified borax of commerce, by one of the following processes:

1. To a solution of borax, in boiling water, add half its weight

of sulphuric acid, previously diluted with an equal quantity of water. Evaporate the solution a little; and, on cooling, shining scaly crystals will appear, which consist of boracic acid. Let them be well washed with distilled water, and dried on filtering paper.

2. Let any quantity of borax be put into a retort, with half its weight of sulphuric acid, and half its weight of water. Boracic acid may be obtained by distillation, and may be purified, by washing in water, &c., as before. By neither of these processes, however, is the acid obtained perfectly pure; for electrical analysis discovers in it a minute portion both of alkali and of sulphuric acid. (Davy.)

II. Boracic acid has the following qualities:

It has the form of thin white scales, is destitute of smell, and nearly so of taste. Its specific gravity is 1.479.

It fuses, when heated, and loses its water of crystallization. This, according to Dr. Thomson, amounts to about 43, to Berzelius 44, parts in 100 of the crystals, which consist, therefore, of one atom of boracic acid and two atoms of water. If the heat be increased suddenly, before it has lost its water of crystallization, boracic acid sublimes; but, otherwise, it melts into a glass, which is permanent in the strongest fire, and has the specific gravity 1.803.

It is generally described as soluble in twelve parts of cold water, and in three or four of boiling water; but, according to Sir H. Davy, even boiling water does not take up above $\frac{1}{10}$ of its weight.

This solution reddens vegetable blue colours, and effervesces with alkaline carbonates. It is remarkable, however, that it reddens turmeric in the same manner as alkalies. (Faraday.)

It is soluble in alcohol, and the solution burns with a beautiful green flame.

Boron with chlorine.—Boron burns with considerable splendour in chlorine gas. The product Berzelius finds to be a new gas, which may be freed from excess of chlorine by standing over mercury. (Ann. of Phil. N. S. x. 127.) It smokes in the atmosphere like fluoboric gas, and consists of

Chlorine - - - - - - - - -	90.743
Boron - - - - - - - - - -	9.257

But the combination of these two elements has been better effected by Despretz, by passing chlorine over boruret of iron, and also by transmitting the same gas, deprived of water, over charcoal and boracic acid, ignited together in a porcelain tube. (Ann. de Chim et de Ph.) It has since been investigated by Dumas. (Same work. xxxiii. 376.) It does not appear, however, that any known process yields it in a state of purity, and it is only from a calculation, involving several data, that Dumas estimates the density of its vapour at 4.0795.

Fluoboric Acid.

With the view of obtaining fluoric acid gas perfectly free from water, Sir H. Davy and Gay Lussac had recourse to the same expedient, *viz.*, that of distilling perfectly dry boracic acid with fluate of lime. When these substances were exposed to a strong heat in an iron tube, in the proportion of one part of the former to two of powdered fluor spar, a gas was collected in great quantity, which exhibited very remarkable properties, and to which Messrs. Gay Lussac and Thenard have given the name of *gas fluoborique*, or fluoboric acid gas. It may, also, be obtained by distilling in a retort one part of vitreous boracic acid with two of fluor spar and 12 of sulphuric acid. Small quantities of fluosilicic gas and sulphurous acid were found by Dr. Thomson to be mingled with it; but making due allowance for these, its specific gravity was 2.3622, agreeing very nearly with Dr. Davy's result (2.3709) in which no correction was made for impurities. Dumas has since determined the specific gravity of the pure gas to be 2.3075. He conceives it to be constituted of 1 volume of gaseous boron and 3 volumes of fluorine, condensed into 2 volumes. (33 Ann. de Chim. et de Ph. 384.)

When potassium or sodium was heated in fluoboric gas, Gay Lussac and Thenard obtained fluate of potassa or soda, and the base of the boracic acid, boron, was separated.

This gas appears to contain no water, and to have so strong an affinity for water, as to take it from other gases which have not been artificially dried. Hence, when mixed with most of those gases, on which it does not exert a chemical action, such as atmospheric air, it causes a cloudy appearance.

Fluoboric gas is absorbed copiously by water, which takes up 700 times its bulk, and acquires the specific gravity 1.77. It is not, however, according to Berzelius, absorbed without decomposition, but deposits boracic acid. (Ann. of Phil. N. S. x. 122, and Ann. de Ch. et de Ph. vol. 29.) The saturated solution has the causticity and aspect of strong sulphuric acid; requires for ebullition a temperature considerably exceeding 212° Fahrenheit; and is condensed again in striæ which contain much gas. From analogy, Gay Lussac supposes that nitric and even sulphuric acids would, if they could be obtained free from water, be equally elastic with this acid.

The liquid acts almost as intensely as sulphuric acid on vegetable substances. It blackens paper, and affords a true ether with alcohol. It has no effect in corroding glass.

With ammoniacal gas fluoboric gas unites in three proportions. If the alkaline gas be put first into the tube, equal measures combine together, and the compound is solid and neutral. But if we admit fluoboric gas by bubbles to the alkaline gas, we obtain a liquid compound, with an excess of base, consisting of one measure of fluoboric gas to two of ammonia; and if to the second compound an additional volume of fluoboric gas be added, it is slowly absorbed, and the product is still liquid. Both fluid compounds, when heated, are rendered solid by the expulsion of part of the ammonia. The solid salt is volatilized, unaltered, at a moderate heat.

From the analysis of the second compound, in which the acid and base are probably present in binary proportion, Dr. Thomson deduces the atomic weight of fluoboric acid to be 34. It consists then of

1 atom fluoric acid - - - -	10
1 atom boracic acid - - -	24
	34

Berzelius finds it to consist of

Fluoric acid - - - -	47.942
Boracic acid - - - -	52.058
	100.

The combinations of fluoboric acid with different bases are fully described by Berzelius in the Essay just quoted.

SECTION V.

Phosphorus.

Phosphorus was discovered about the year 1669 by Brandt, an alchemist of Hambargh, while employed in the research after the art of converting the baser metals into gold and silver; and afterwards by Kunckel, a German chemist. But the method of preparing it was not publicly divulged by either of those persons; and it was not till 1737, that a commission, appointed by the [illegible] Academy of Sciences, was instructed by a stranger in the [illegible]. It consisted in evaporating putrid urine to dryness, and distilling the residuum at an intense heat in a stoneware retort. [illegible] improved the process by adding a salt of lead to the urine; [illegible] 1769 Gahn, of Sweden, having discovered the phosphoric [illegible] bones, invented the method of preparing phosphorus which is now generally adopted, and will presently be described.

Phosphorus is an inflammable substance, and is distinguished by the following external characters.

It has generally a flesh-red colour, [illegible] may be obtained colourless and perfectly transparent. [illegible] gravity is 1.77. It is necessary to [illegible] closed bottles.

It is so soft that it [illegible] yields to the [illegible].

It melts at about 10[illegible] [illegible] must be covered with [illegible]. Under certain circumstances [illegible] at temperatures [illegible] but [illegible] temperature, and especially by the smallest fragment of phosphorus. Quart. Journ. Jan. [illegible].

Exposed to a heat of [illegible] it, and suddenly cooled, it becomes black; but, if slowly congealed, it remains transparent and colourless; when cooled at a moderate rate, it assumes the semi-transparency of horn. According to Thenard however, it is not all phosphorus that exhibits these properties, but only that which has undergone repeated distillations. Mitscherlich has crystallized phosphorus, from a solution of phosphuret of sulphur, in the form of rhombic dodecahedrons; and by the fusion and careful refrigeration of a large quantity, crystals have been obtained as large as cherry-stones, and of an octahedral figure. (Phil. Mag. and Ann. Phil. iii. 154.)

In the atmosphere phosphorus emits a white smoke, and a peculiar smell resembling that of garlic; and a faint and beautiful light arises from it; but these appearances do not take place in air which has been artificially dried. If a cylinder of phosphorus be introduced into a vessel of oxygen gas over mercury, at a temperature not exceeding 80° Fahrenheit, no perceptible absorption will happen in 24 hours; but if, the temperature remaining the same, the pressure be diminished to $\frac{1}{8}$th or $\frac{1}{10}$th that of the atmosphere, the phosphorus will be surrounded by white vapours, will become luminous in the dark, and will absorb oxygen. Under ordinary pressures, a higher temperature is required to produce this effect; but it is remarkable, that if the density of the oxygen be reduced in the above proportion, by mixing it with azote, hydrogen, or carbonic acid, the phosphorus becomes luminous. From atmospheric air of ordinary density and temperature, phosphorus slowly absorbs oxygen, with an extrication of light.

Phosphorus is inflamed by the application of a very gentle heat. According to Dr. Higgins, a temperature of 60° is sufficient to set it on fire, when perfectly dried by blotting-paper.

It burns when heated to about 148°, with a very brilliant light, a white smoke, and a suffocating smell, and may even be inflamed in an atmosphere rarefied sixty times. (Van Marum.) It may also be set on fire by friction; for example, when rubbed between two pieces of brown paper.

In oxygen gas phosphorus burns with a most brilliant light; and also in nitrous oxide, nitrous, and chlorine gases. The product of the rapid combustion of phosphorus in oxygen gas is exclusively phosphoric acid, which appears in white flakes like snow. These when exposed to the air rapidly absorb moisture, and become liquid.

At 550° Fahr. phosphorus is volatile; but its vapour is immediately condensed again into a liquid by lower temperatures. From various data, Dumas has calculated the density of its vapour at 2.2052. (Ann. de Ch. et de Phys. Dec. 1826.)

The only information, which we possess, respecting the *nature of phosphorus*, is derived from the electro-chemical researches of Sir H. Davy. When acted upon by a battery of 500 pairs of plates in the same manner as sulphur, gas was produced in considerable quantities, and the phosphorus became of a deep red-brown colour. The gas proved to be phosphureted hydrogen, and was equal in bulk to about four times the phosphorus employed. Hence hydrogen may possibly be one of its components; but no confirmation of the truth of this view is derived from the recent experiments of the same philosopher, which, indeed, are rather contradictory to it.

Art. 1.—*Phosphorus and Oxygen.*

Phosphorus may be oxygenized in various modes.

1. *By exposure to atmospheric air.*—If a stick of phosphorus be placed in a funnel, the pipe of which terminates in an empty bottle, the phosphorus slowly acquires oxygen, and forms an acid, which falls into the bottle in a liquid state. A large quantity of acid may be obtained, if a number of sticks be thus exposed; but as they would be in danger of taking fire, if heaped together, each stick should be separately enclosed in a glass tube. These tubes must be disposed round a funnel, the pipe of which terminates in a bottle. The whole should be covered by a bell-shaped receiver, the air of which is to be frequently changed. The acid thus obtained is a mixture of *phosphorous* and *phosphoric* acids, &c. Dulong, indeed, believes it to be a distinct compound, for which he has proposed the name of *phosphatic acid.* (Phil. Mag. xlviii. 273.) But this view of its composition is not supported by the more recent investigations of Sir H. Davy, who still considers it as a mixture of the two known acids of phosphorus.

Phosphorus, kept under water in a bottle, partly filled with that fluid, and into which fresh air is occasionally admitted, becomes slowly changed, partly into a soluble acid which the water takes up, and partly into a white substance that invests the sticks of phosphorus with an insoluble covering. This appears to be an oxide of phosphorus. The change, it has been found by Mr. R. Phillips, is facilitated by exposure to light; and in that case water is decomposed, and phosphureted hydrogen, with phosphorous and phosphoric acids, are generated.

When phosphorus is burned in a quantity of atmospheric air much short of that which is required to consume it, the unburned portion consists of a red oxide, mixed with unconsumed phosphorus and phosphoric acid. The red substance is an oxide of phosphorus, but neither the precise composition of this, nor of the white oxide, has been yet ascertained. It has been conjectured, indeed, that the white compound is a *hydrate*, composed of water united with the red oxide. (On the Oxides of Phosphorus, see Nicholson's Journal, vi. 134.)

When phosphorus is burnt in highly rarefied air, three products are formed—a red solid comparatively fixed, and requiring a heat above 212° for its fusion—a white and easily volatile substance, which is combustible, soluble in water, and has acid properties; and a substance which is strongly acid and not volatile even at a white heat. The first appears to be a mixture of unburned phosphorus and phosphorous acid; the second to be phosphorous acid; and the third to be phosphoric acid. (Davy.)

2. *Phosphorus inflames vividly in oxygen gas.*—When burnt in this manner over mercury, every hundred parts of phosphorus, according to Lavoisier, gain an addition of 154. Sir H. Davy at first determined that 100 grains of phosphorus condense, by rapid combustion, 450 cubic inches, or 153 grains, of oxygen gas; but hav-

ing examined the subject anew, with every attention to the accuracy of his results, and with the advantage of improved methods of operating, he found that, taking an average of three experiments, 100 grains of phosphorus combine with only 135 grains of oxygen. Considerations, derived from the determination of the atomic weight of phosphoric acid, to be afterwards stated, render it probable that the true proportions are 100 of phosphorus to 133$\frac{1}{3}$ oxygen.

3. *Oxygenation by nitric acid.*—If phosphorus be cautiously added, by small fragments at once, to nitric acid, gently heated in a retort, the nitric acid is decomposed, nitrous gas escapes abundantly, and the oxygen of the acid, uniting with the phosphorus, constitutes phosphoric acid. A tubulated retort must be used for this purpose; and its neck may terminate in the apparatus already described for procuring nitric acid. By this contrivance a considerable quantity of nitric acid will be saved. The liquid, remaining in the retort, may be evaporated in an open platinum vessel to a thick consistence, the heat, towards the last, being raised to redness. This expels the redundant nitric acid, and also drives off a portion of ammonia, which Mr. R. Phillips has observed to be formed by the action of phosphorus on nitric acid, the nitrogen of which unites with hydrogen, liberated at the same moment by the decomposition of water.

Process for preparing Phosphoric Acid from Bones.

1. To prepare this acid on a large scale, the combustion of phosphorus would be much too expensive. The following is the most economical method:

On 20 pounds of bone, calcined to whiteness and finely powdered, pour 20 quarts of boiling water, and add 16½ pounds* of sulphuric acid, diluted with an equal weight of water. Let these materials be well stirred together, and be kept in mixture about twenty-four hours. Let the whole mass be next put into a conical bag of sufficiently porous and strong linen, in order to separate the clear liquor, and let it be washed with water, till the water ceases to have much acidity to the taste. Evaporate the strained liquor in earthen vessels, placed in a sand-heat, and, when reduced to about half its bulk, let it cool. A white sediment will form in considerable quantity, which must be allowed to subside; the clear solution must be decanted, and boiled to dryness in a glass vessel. A white mass will remain, which is the dry phosphoric acid. This may be fused in a crucible, and poured out in a clean copper dish. A transparent glass is obtained, which is the phosphoric acid in a glacial state; not, however, pure, but containing much sulphate and phosphate of lime. According to Fourcroy and Vauquelin, it is, in fact, a super-phosphate of lime, containing, in 100 parts, only 30 of uncombined phosphoric acid, and 70 of neutral phosphate of lime; but, when prepared with the full proportion of sulphuric acid, Mr. Dalton finds only from 8 to 12 *per cent.* of the calcareous phosphate. To separate the latter, Dr. Higgins neutralized the acid liquor, obtained by the action of sulphuric acid on bones, with carbonate of ammonia; the neutral liquor was decanted and evaporated till a portion of it deposited crystals on cooling; and was then poured, while hot, into a thin glass balloon, which was placed on the sand bed of a reverberatory furnace. The mouth of the balloon being covered with an inverted crucible, the fire was gradually raised till the sand pot was obscurely red. In this way, the sulphate of ammonia, and ammonia that neutralized the phosphoric acid, were both expelled; and the atmospheric acid remained in the form of a transparent colourless glass, still retaining a minute quantity of ammonia. (Minutes of a Society, p. 252.) The glacial acid, in its purest form, still contains, also, according to Dulong, 17.08 per cent., according to Rose only 9.44 per cent. of combined water, which cannot be expelled without volatilizing the acid itself.

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* These are the proportions recommended by Pelletier and Dalton. A much less quantity of sulphuric acid is generally prescribed.

The phosphoric acid has the following properties:

When pure and glacial, it dissolves readily in water. That obtained immediately from bones is rendered insoluble by the admixture of earthy salts; but the glacial acid prepared with nitric acid is readily soluble. Its taste is intensely sour, but it does not corrode animal substances.

The solution is not volatile, nor capable of being decomposed by heat only; nor does it emit any smell when heated.

Phosphoric acid may be discriminated from all others by neutralizing a portion with pure carbonate of soda or of potassa, and passing through it a stream of sulphureted hydrogen. No change is produced; but by a solution of acetate of lead the diluted acid is precipitated white; and by nitrate of silver, yellow. The former precipitate, phosphate of lead, is soluble in nitric or phosphoric acid; the second, phosphate of silver, is dissolved by both those acids and by ammonia. (Turner's Elem. of Chem.)

The following Table shows the composition of phosphoric acid according to different authorities. According to

Rose - - -	100 phosphorus are combined with	114.6 oxygen.
Dulong - -	100 - - - - - - - - - - - -	124.8
Berzelius - -	100 - - - - - - - - - - - -	127.5
Davy - - -	100 - - - - - - - - - - - -	135.

The want of agreement between these results shows that it is not easy to determine the composition of phosphoric acid by the direct union of its base with oxygen, or even, as attempted by Dulong, with chlorine, or by Dumas, with phosphureted hydrogen. The result of Davy approaches most nearly to the proportion of 12 (1 atom) of phosphorus to 16 (2 atoms) of oxygen.

Process for obtaining and purifying Phosphorus.

When distilled in an earthen retort, with half its weight of powdered charcoal, glacial phosphoric acid is decomposed; its oxygen uniting with the carbon, forms carbonic acid; and phosphorus, in quantity equal to only about one-fourth of the acid, rises in a separate state, a great proportion of it escaping in combination with hydrogen. This is the usual and best mode of obtaining phosphorus.

The phosphoric acid of bones may either be employed for this purpose in the state of glass, finely powdered; or to the evaporated acid, when acquiring a thick consistence, powdered charcoal may be added in sufficient quantity to give it solidity. In the latter mode, however, unless the heat is very cautiously raised, the materials are apt to swell, and to boil over. The mixture of acid and charcoal is to be put into a stoneware retort, coated with Willis's lute, the neck of which is lengthened out by a tin pipe. The open end of the pipe is to be immersed in a vessel of water. The heat is to be slowly raised, and at length made very intense. An enormous quantity of gas escapes, which takes fire on coming into contact with the atmosphere; and the phosphorus distils over in drops, which congeal in the water. As it is apt also to condense in, and to stop up, the neck of the retort and tin pipe, it must be occasionally melted out of these, by a shovelful of hot cinders held under them. The process is rather a troublesome one; and, though it is proper that the student should for once perform it, it will be found more economical to purchase the phosphorus which may be required for use; and to purify it, for purposes of accurate research, in the following mannner:

The quantity of phosphorus, which it is intended to rectify, must first be put into a retort, with a sufficient portion of water to cover it; and the water then made hot enough to melt the phosphorus, which, on cooling, forms a compact mass, of the shape of the bottom of the retort. When cold, fill the retort, and its neck also, with water, and invert it in water. Displace the water by hydrogen gas, forced from a bladder through a bent pipe; keep the finger on the open end of the retort neck; place it in a sand bath; and immerse the mouth of it in water. Then apply heat very cautiously. A bladder should also be provided, furnished with a stop-cock and brass pipe, and filled with hydrogen gas. During the distillation, the gas in the retort is absorbed, and it is necessary to add more from the bladder, otherwise the water will rush into the retort, and occasion an explosion. By distillation, in this mode, phosphorus is rendered much purer. In the neck of the retort, a substance is condensed of a beautiful red or carmine colour, which is a combination of carbon and phosphorus, or a *phosphuret of carbon*. Thenard observes that phosphorus, however frequently distilled, cannot be freed entirely from charcoal, a minute quantity of which does not seem to impair its whiteness or transparency.

Phosphorus may also be procured by adding to urine a solution of lead in nitric acid, which precipitates a phosphate of lead. This, when well washed, dried, and distilled in a stoneware retort, yields phosphorus. (Crell's Journal, Translation, iii. 36.) Or a solution of phosphate of soda (which may be bought of the druggists,) mixed with one of acetate of lead, in the proportion of one part of the former salt to 1¼ of the latter, yields a precipitate of phosphate of lead, from which phosphorus may be procured by distillation with charcoal, but at considerably more expense.

Phosphorous Acid.

Phosphorous acid cannot, according to Sir H. Davy, be obtained pure by exposing cylinders of phosphorus to atmospheric air; for, when thus prepared, it always contains phosphoric acid. It can only be procured in a state of purity, by first subliming phosphorus through corrosive sublimate; then mixing the product with water, and heating it, till it becomes of the consistence of syrup. The liquid obtained is a compound of pure phosphorous acid and water, which becomes solid and crystalline on cooling. It is acid to the taste, reddens vegetable blues, and unites with alkalies, forming salts called *phosphites*. By exposure to the air, these salts pass to the state of *phosphates*.

The theory of its production is, that when the compound of phosphorus and chlorine, formed in the first operation, is brought into contact with water, the water is decomposed; its hydrogen uniting with chlorine composes muriatic acid; and, its oxygen combining with phosphorus, forms phosphoric acid. From this mixture of acids, heat expels the muriatic only.

The phosphorous acid exhales a disagreeable fœtid odour; and yields, when strongly heated, penetrating white vapours. By the attraction of its base for more oxygen, it precipitates the perfect metals from their solutions in a metallic form. When heated in a glass ball, blown at the end of a small tube, a gas issues from the orifice of the tube, which inflames on coming into contact with the atmosphere. The residuum in the ball is phosphoric acid. From the experiments of Rose on the phosphoric acid, Gay Lussac infers that phosphorous acid must consist of

Phosphorus	56.81	100	10.52
Oxygen	43.19	76	8.
	100.		

These proportions do not differ materially from those stated by Dulong, who makes phosphorous acid to consist of 100 phosphorus + 74.88 oxygen. (Phil. Mag. xlviii. 273.)

Sir H. Davy, after a careful investigation of the constitution of phosphorous acid, has been led to conclude that the oxygen which it contains is just one-half of that existing in phosphoric acid; or that, in the former, 100 grains of phosphorus are united with only 67.5 of oxygen. Hence phosphorous acid must consist of

Phosphorus	59.7	11.83
Oxygen	40.3	8.
	100.	

And if phosphorous acid be constituted of 1 atom of oxygen + 1 atom of phosphorus, the weight of the latter atom may be inferred to be 11.83, or in round numbers 12. Phosphorous acid, then, will be represented by 12 + 8 = 20.

It must be acknowledged, however, that there is still room for doubt, respecting the true atomic constitution of this and other compounds of phosphorus with oxygen. Berzelius and Dulong deduce the proportion of oxygen in the phosphorous acid to be to that in the phosphoric as 3 to 5, while Davy and Thomson conclude it to be as 3 to 6. Dumas, despairing of satisfactory results from a mere repetition of the experiments of such accurate chemists, attempted a new mode of investigation, which led him to infer, with Berzelius, that the true proportion is that of 3 to 5. (31 Ann. de Ch. et de Phys. 112.) Now if phosphoric acid be constituted, as has been shown to be probable, of 16 oxygen + 12 phosphorus, the phosphorous acid should consist very nearly of 12 phosphorus + 9.6 oxygen, for 5 : 3 : : 16 : 9.6. But this is improbable, because it is at variance with the law of multiple proportions; 16 being no simple multiple of 9.6.

Hypo-phosphorous Acid.

When phosphuret of baryta, carefully prepared, is made to act on water, two distinct compounds are generated, *viz.*, phosphate of baryta, which, being insoluble, is readily separated by filtration; and a soluble salt of baryta, which passes through the filter. To the latter compound, sulphuric acid is to be added, in quantity just sufficient to separate the baryta. The acid solution which remains, when concentrated by evaporation, yields a viscous fluid, strongly acid and uncrystallizable. By a still stronger heat, this substance is decomposed; proto-phosphuretted hydrogen is developed; a little phosphorus is sublimed; and phosphoric acid remains in the retort. (Dulong, 48 Phil. Mag. 271.)

The compounds of this new acid, with alkaline and earthy bases, are remarkable for their extreme solubility. Those of baryta and strontia crystallize with great difficulty. The *hypo-phosphites* of potassa, soda, and ammonia, are soluble, in all proportions, in highly-rectified alcohol. That of potassa is even more deliquescent than chloride of calcium. They absorb oxygen slowly from the air, and, when heated in a retort, give the same products as the acid itself. An able memoir by Rose, on this class of salts, may be consulted in Ann. de Ch. et de Phys. July 1828.

In order to ascertain the proportions of the elements of this acid, Dulong, its discoverer, converted a known quantity of it into phosphoric acid by means of chlorine, whence he infers it to consist of

Phosphorus - -	72.75 -	100. -	21.36
Oxygen - - -	27.25 -	37.44 -	8.
	100.		

These results lead to the supposition that hypo-phosphorous acid is a compound of 1 atom of oxygen + 2 atoms of phosphorus; but it is still doubtful whether it may not be a triple compound of oxygen, phosphorus, and hydrogen, or a *hydracid;* in which case its proper appellation would be *hydro-phosphorous acid.*

In his able investigation of the compounds of phosphorus, Sir H. Davy admits the existence of the new acid of Dulong, but deduces somewhat different proportions of its elements. The oxygen of this acid he concludes to be precisely half of that which exists in phosphorous acid; or that 100 of phosphorus are united with 33.750 oxygen. If this were correct, it would confirm the notion that hypo-phosphorous acid is constituted of 1 atom of oxygen weighing 8, and 2 atoms of phosphorus weighing 12 × 2 = 24, and that the weight of the compound atom is represented by 32. But here, again, there is a want of agreement respecting facts, for Rose, by a more recent set of experiments, has arrived at the conclusion, that in hypo-phosphorous acid, 100 phosphorus are united with only 25.61 oxygen, or with about one-third the oxygen constituting phosphorous acid, at least viewing the latter acid as stated by Berzelius and Dulong. (Ann. de Ch. et de Ph. Aug. 1827.)

So far as we have at present the means of judging, the following Table appears to me to represent the most probable constitution of these compounds:

	Atoms of Phosph.		Atoms of Oxyg.	Weight of Atom.
Hypo-phosphorous acid - -	2	+	1 -	32
Phosphorous acid - - - -	1	+	1 -	20
Phosphoric acid - - - -	1	+	2 -	28

But the subject, it is obvious, admits of another view, which derives some probability from the analogy of the compounds of sulphur and oxygen, *viz.*, that hypo-phosphorous, phosphorous, and phosphoric acids, may be respectively compounded of 1 atom of phosphorus, with 1, 2, and 3 atoms of oxygen. It is true that such a proportion of oxygen as that of 2 to 3 in phosphorous and phosphoric acids, does not agree either with the results of Berzelius and Dulong, or with those of Davy; but where the discrepancies are so great as to facts, some latitude may be allowed as to theoretical deductions.

ART. 2.—*Combinations of Phosphorus with Chlorine.*

There are two compounds of chlorine and phosphorus.

1. *Bi-chloride or Per-chloride.*—When phosphorus is introduced into chlorine gas, it takes fire spontaneously, and burns with a pale flame; and a white solid condenses on the sides of the vessel. In an experiment of Sir H. Davy, conducted with great care, 4 grains of phosphorus condensed 31.9 cubic inches (barometer 30.1, thermometer 46°) of chlorine gas, equivalent to very nearly 24½ grains, or six times its weight. Therefore 100 grains of phosphorus, to form this compound, condense 600 grains of chlorine; and as 36 of chlorine appear, from a variety of facts, to be equivalent to 8 of oxygen, the above 600 grains are, by the rule of proportion, the equivalent of 135 of oxygen; and thus is derived a collateral proof that phosphoric acid is constituted of 100 phosphorus, and

very nearly 135 oxygen by weight, the true proportion of oxygen being 133⅓.

The solid compound of phosphorus and chlorine is volatile at a temperature below 212° Fahr. It acts violently on water, the hydrogen of which forms, with the chlorine, muriatic acid; while the oxygen forms, with the phosphorus, phosphoric acid. When transmitted with oxygen gas through a red-hot porcelain tube, chlorine is evolved, and phosphoric acid is formed, showing that, at high temperatures, the affinity of oxygen for phosphorus is stronger than that of chlorine.

2. *Chloride or Proto-chloride.*—Though this compound may be obtained by heating the per-chloride with a due proportion of phosphorus, yet a better method of preparing it is (as Sir H. Davy recommends) to pass the vapour of phosphorus over corrosive sublimate, heated in a glass tube. By this process, proto-chloride of mercury (calomel) is formed, and the remaining atom of chlorine unites with the phosphorus. The result is a liquid of the specific gravity 1.45, which does not itself redden litmus paper, though its fumes produce this effect, in consequence of being [illegible]dered acid by contact with the moisture of the air. The [illegible] which results from its action on water is the.phosphorous, which is best procured by the intervention of this chloride. At the same time muriatic acid is formed, by the union of chlorine with the hydrogen of the water.

In this compound, the chlorine exists in half the quantity which constitutes the per-chloride, that is, 100 grains of phosphorus are united with 300 of chlorine. But in phosphorous acid, 100 grains of phosphorus are combined with 67.5 of oxygen, which last number is, therefore, the equivalent of 300 chlorine. Now as 67.5 to 300, so is 8 to 36; indicating that in the *chloride* of phosphorus its elements are united atom to atom, while in the *per-chloride*, two atoms of chlorine are combined with one of phosphorus.

	Atoms of Phosph.		Atoms of Chlor.		Weight of Atom.
Chloride of phosphorus -	1	+	1	-	48
Per-chloride - - - - - -	1	+	2	-	84

ART. 3.—*Phosphorus with Iodine.*

Phosphorus and iodine combine at the temperature of the atmosphere, according to Sir H. Davy, evolving much heat, but no light; but, according to Thenard, with a disengagement both of light and heat, a difference which Dr. Traill has shown to depend upon the way in which the experiment is performed. If the phosphorus be completely covered with iodine, no light is visible. The result is an *iodide of phosphorus*, of a reddish brown colour, the solidity, fusibility, and volatility of which vary with the proportions of its ingredients. If both the phosphorus and iodine are dry, no gas is given out during their combination; but, when slightly moistened, hydriodic acid is formed, by the union of iodine with the hydrogen of the water; a little subphosphureted hydrogen is produced; and phosphorous acid remains in solution. The hydriodic acid gas is also formed when the phosphuret of iodine, produced from dry materials, is added to water.

SECTION VI.

Sulphur.

Sulphur, as it occurs in commerce, is a mineral production, and is brought to this country chiefly from Sicily. That which is procured in our own island is generally of very inferior quality, and contains a portion of the metal, from combination with which it has been separated. It is met with under two different forms; of a compact solid, which has generally the shape of long rolls or sticks; and of a light powder called *flowers of sulphur*. In general, the latter may be considered as most pure; but the two varieties, it will presently appear, are readily convertible into each other by the modified application of heat. Its specific gravity is 1.98 or 1.99. When rubbed, it emits a peculiar smell, and becomes negatively electric.

Sulphur is readily fused and volatilized. When heated to 170° of Fahr., it begins to evaporate, and to produce a very disagreeable smell; at 185° or 190° it begins to melt; and at 220° (227° Dumas) is completely fluid. If the heat be rapidly increased, it loses at 350° its fluidity, and becomes firm, and of a deeper colour. It regains its fluidity, if we reduce the temperature; and this may be repeated at pleasure, in close glass vessels, if the changes of heat be not too slow; in which case it is volatilized. When liquefied sulphur, of a temperature not exceeding 340° Fahr., is suddenly cooled by pouring it into water, it becomes friable, and has its usual colour and opacity.

It sublimes at 600°; and, according to the greater or less quickness of the process, and the size of the condensing chamber, may be collected either in a solid form or in that of flowers. (Thenard, i. 197.) What remains has been called *sulphur vivum*. This affords an example of the process of *sublimation*, which differs from distillation, in the solidity of the product, while the latter yields a condensed liquid. In this mode, sulphur may, in part, be purified; and its purification is completed by boiling it repeatedly in distilled water; then in twice or thrice its weight of nitro-muriatic acid, diluted with one part of distilled water; and, finally, by washing it with distilled water, till this comes off tasteless, and incapable of changing the blue colours of vegetables.

Fused sulphur, under certain circumstances, continues fluid, as water does, several degrees below its congealing point, but instantly solidifies when touched by a rod of glass, or by a fragment of solid sulphur. (Quart. Journ. Jan. 1828, p. 469.) If, after being melted, it be suffered to cool gradually, it congeals in a crystalline form, but so confusedly, that we cannot define the shape of the crystals, farther than that they are slender interlaced fibres. If a large mass be kept fluid below, while it congeals at the surface, the crystallization there is much more distinct. M. Mitscherlich has made the discovery of two primary forms of sulphur. The one, which occurs in nature, is an octahedron with a rhombic base; the other, produced by the slow cooling of fused sulphur, is an oblique rhombic prism. When sulphur in complete fusion, *viz.* at 300°, (from 380° up to 500° Dumas,) is poured into water, it becomes tenacious like wax, and may be applied (as is done by Mr. Tassie) to take impressions from engraved stones, &c. These impressions are quite hard, when the sulphur has become cold. It is then of a red colour, rather soft, and of the specific gravity 2.325. The phenomena of its being cooled under different circumstances have been lately examined by Dumas. (Ann. de Ch. et de Ph. xxxv. 83.)

When flowers of sulphur are digested in alcohol, no union takes place; but if the two bodies be brought into contact, when both are in a state of vapour, they enter into chemical union. Into a glass alembic (see the plates to this work, fig. 2) put a little sulphur; over this suspend a small bottle filled with alcohol; and apply a receiver to the pipe of the alembic, the head being put into its place. Lute the junctures, and apply a gentle heat to the alembic. The sulphur will now be raised in vapour; and the vapour surrounding the bottle of alcohol, the latter will be volatilized, and will meet in this state the fumes of sulphur. A combination will take place between the two bodies, and sulphurized alcohol will pass into the receiver. On pouring this preparation into water, the sulphur will be precipitated.

Sulphur is perfectly soluble in boiling oil of turpentine, which may be employed as a means of determining its purity.

Though it had already been suspected (chiefly from the experiments of M. Berthollet, jun.) that sulphur contains hydrogen, yet the first unequivocal evidence of the fact was furnished by Sir H. Davy. A bent glass tube, having a platinum wire hermetically sealed into its upper extremity, was filled with sulphur. The sulphur was melted by heat; and a proper connexion being made with the Voltaic apparatus of 500 double plates, each six inches square and highly charged, a most intense action took place. A very brilliant light was emitted; the sulphur soon entered into ebullition; elastic matter was evolved in great quantities; and the sulphur, from being of a pure yellow, became of a dark reddish brown tint. The gas was found to be sulphureted hydrogen, and its quantity, in about two hours, was more than five times the volume of the sulphur employed.

Another proof of the presence of hydrogen in sulphur is derived from the action of potassium; for these two bodies combine with great energy, and evolve sulphureted hydrogen, with intense heat and light.

Lastly, when dry sulphur is burned in dry oxygen gas, Sir H. Davy is of opinion that, besides sulphuric acid, a portion of water is also formed; but he is still doubtful whether the hydrogen in sulphur can be considered as any thing more than an accidental ingredient. This view of the subject is embraced, also, by Berzelius, who found, by heating sulphur with oxide of lead, that the quantity of water produced is much too minute to indicate any definite proportion of hydrogen in sulphur. (79 Ann. de Chim. 119.)

Another ingredient of sulphur, it appeared probable from the experiments of Sir H. Davy, is oxygen. For potassium, after being made to act on sulphureted hydrogen gas, evolved less hydrogen from water, than it ought to have done. It has since, however, been proved by Gay Lussac, that when all sources of fallacy are avoided, a given weight of potassium, which has been exposed to sulphureted hydrogen, separates exactly the same volume of hydrogen gas from water, as an equal weight of recent metal. Potassium, therefore, acquires no oxygen, from the sulphur which is contained in sulphureted hydrogen. (Ibid. vol. lxxiii.)

Art. 1.—*Sulphur with Oxygen.*

Sulphur is inflammable, and appears susceptible of two distinct combustions, which take place at different temperatures. Heated in the open air, to 140° or 150° Fahr., it begins sensibly to attract oxygen; and if the temperature be raised to 180° or 190°, the combination becomes pretty rapid, accompanied by a faint blue light. But the heat evolved is scarcely sensible; at least it is so weak, that the sulphur may thus be burned out of gunpowder, and the powder be rendered useless without inflaming it. At a temperature of 300°, its combustion, though still feeble compared with that of some other bodies, is much more active, and accompanied with a redder light. When set on fire in oxygen gas, it burns with a very beautiful and brilliant light: but of a given quantity of oxygen gas, it is not possible to condense the whole by this combustion, for reasons which hereafter will be stated. The product of these combustions, when examined, will be found to be sulphurous and sulphuric acid, but chiefly the former, and if water be carefully excluded, sulphurous acid only is formed. It is necessary, therefore, in order to produce sulphuric acid, to make the experiment over water.

Sulphuric Acid.

Sulphuric acid has been known ever since the time of Basil Valentine, who appears to have discovered it about the close of the 15th century. It was first extracted from sulphate of iron by distillation, and was afterwards formed by the combustion of a mixture of about 1 part of nitre and 6 or 8 of sulphur in large glass vessels, over water. For glass vessels, in process of time, large leaden chambers, having a stratum of water floating on the bottom, came to be substituted. The history of the successive improvements of its manufacture in this country has been given at length by Mr. Parkes, in the second volume of his Chemical Essays.

The properties of this acid may be exhibited by a portion of that usually found in the shops. They are as follows:

Sulphuric acid has a thick and oily consistence; as may be seen by pouring it from one vessel into another. In a pure state it is perfectly limpid and colourless.

Action of water.—When mixed suddenly with water, considerable heat is produced. Four parts, by weight, of concentrated sulphuric acid, and one of water, when mixed together, each at the temperature of 50° Fahr., have their temperature raised to 300°. When an ounce of water has been suddenly mixed with three of sulphuric acid, and the mixture been suffered to cool to the temperature of the atmosphere, an additional half oz. of water raises it to 86°, a second to 96°, and a third to 104°. (Phillips on the London Pharmac. p. 24.) The greatest elevation of temperature, Dr. Ure finds to be occasioned by the sudden mixture of 73 parts by weight of strong sulphuric acid with 27 of water. This rise of temperature takes place, because the affinity or capacity of the compound of sulphuric acid and water for caloric, is less than that of the acid and water separately. A diminution of bulk also ensues; that is, one measure of acid and one of water do not occupy the space [illegible] two measures, but about $\frac{1}{75}$th less; and the greatest condensation results, when those proportions are used, which give the greatest increase of temperature. Owing to the heat produced by its admixture with water, the dilution, for ordinary purposes, should be conducted very gradually; and the acid should be added to the water by small portions at once, agitating the mixture after each addition, and allowing each portion to cool before a fresh addition is made. On the principle of its attraction for water is to be explained, also, the rapid increase of weight which the sulphuric acid acquires when exposed to air. In one day, three parts of concentrated sulphuric acid, exposed to the atmosphere, are increased [illegible] weight one part; and one ounce, by twelve months' exposure, [illegible] been found to gain an addition of 6¼.

Perfectly pure sulphuric acid remains quite limpid during dilution. The sulphuric acid, however, commonly found in the shops, under the name of *oil of vitriol*, on admixture with water, deposits a white powder, in considerable quantity, consisting of various impurities, but chiefly of sulphate of lead. By evaporating 100 parts of sulphuric acid of commerce in a platinum dish, Dr. Ure obtained from one half to three quarters of a grain of solid matter, consisting of about two parts of sulphate of potassa and one of sulphate of lead. (Quart. Journ. iv. 115.) Berzelius has found a minute quantity of titanium in sulphuric acid of English manufacture, and tellurium in acid prepared at Stockholm. (Thomson's Annals, x. 464.) Selenium also has been met with in sulphuric acid prepared from pyrites.

Specific gravity.—Sulphuric acid is nearly twice as heavy as water. The specific gravity of the strongest pure acid that can be obtained is 1.850; but even this contains 19 (according to Dr. Wollaston, 18.44) per cent. of water, which appears essential to its constitution, and can only be separated by combining the acid with a base. Dr. Ure states that genuine commercial acid should not exceed 1.8485. When denser, its purity may be suspected. It has been ascertained, by Mr. Dalton, that acid, of nearly the maximum strength, has its specific gravity very little altered, by adding or subtracting small portions of water. Thus acids, containing 81 and 80 per cent. of acid, do not differ more than 1 in the third place of decimals; nor is the specific gravity proportionally changed by dilution till it falls as low as 1.78. The strength of the more concentrated acid may be better ascertained by observing how much water is required to bring it down to the specific gravity 1.78. The boiling point, also, Mr. Dalton has discovered, is a much better test of its strength; and he has constructed the following useful Table, in which account is taken of all these circumstances.

Mr. Dalton's Table of the Quantity of real Acid in 100 *Parts of Liquid Sulphuric Acid, at the Temperature* 60° *Fahr.*

Atoms Acid Water.	Real Acid per cent. by Weight.	Real Acid per cent. by Measure.	Specific Gravity.	Boiling Point.
1 + 0	100	unknown.	unknown.	unknown.
1 + 0	81	150	1.850	620°
	80	148	1.849	605°
	79	146	1.848	590°
	78	144	1.847	575°
	77	142	1.845	560°
	76	140	1.842	545°
	75	138	1.838	530°
	74	135	1.833	515°
	73	133	1.827	501°
	72	131	1.819	487°
	71	129	1.810	473°
	70	126	1.801	460°
	69	124	1.791	447°
1 + 2	68	121	1.780	435°
	67	118	1.769	422°
	66	116	1.757	410°
	65	113	1.744	400°
	64	111	1.730	391°
	63	108	1.715	382°
	62	105	1.699	374°
	61	103	1.684	367°
	60	100	1.670	360°
1 + 3	58.6	97	1.650	350°
	50	76	1.520	290°
	40	56	1.408	260°
1 + 10	30	39	1.30+	240°
1 + 17	20	24	1.200	224°
1 + 38	10	11	1.10—	218°

It has been ascertained by Dr. Ure, that, by adding about 2½ per cent. of its weight of sulphate of potassa to concentrated oil of vitriol, its specific gravity may be increased to 1.860. The only mode, therefore, of ascertaining exactly the strength of oil of vitriol, is by saturating a known quantity with an alkali. Of these, the carbonate (sub-carbonate) of soda, deprived of all its water by calcination, is best adapted to the purpose, and it is sufficiently near the truth for practical purposes to consider 90.75 of this alkali as equivalent to 100 grains of liquid sulphuric acid.

It is sometimes of importance to the chemical artist to know the proportion, not of *real acid*, but of *acid of commerce*, in diluted sulphuric acid of different specific gravities. An approximation to the true proportion may be obtained, by increasing the numbers, indicating the real acid, one-fourth. For example, acid of the specific gravity 1.200, contains, according to the above table, 20 per cent. of real acid; which, increased one-fourth, gives 25 per cent. of acid of sp. gr. 1.849. A very copious table of the quantities of sulphuric acid of commerce in acid of different densities, constructed by Mr. Parkes from actual experiment, is given in the 40th volume of the Philosophical Magazine, and in volume ii. of his Chemical Essays, p. 144. Its length prevents me from inserting it. The shorter table of Vauquelin, in the 30th volume of Nicholson's Journal, is rendered less fit for the English chemist, because the acid, employed in the experiments on which it is founded, is inferior in density to the average acid sold in this country. In taking the specific gravity of sulphuric acid, it is of importance to attend to its temperature, which must be examined by a thermometer having its bulb perfectly dry. According to Dr. Ure, 10° Fahrenheit make a difference in the density of oil of vitriol of 0.005. With due attention to this, and other necessary precautions, Dr. Ure has constructed a table, which, as it is of moderate length, and exhibits at one view the proportion not only of real or dry acid, but of liquid acid, in sulphuric acid of different specific gravities, I shall insert in the Appendix. In the memoir of which the table forms a part, Dr. Ure has endeavoured to establish some general formulæ for calculating the proportion of oil of vitriol in dilute acid of any specific gravity, and also for finding the specific gravity corresponding to a given proportion of acid. (Journ. of Science, iv. 127.)

Congelation.—Sulphuric acid, by a sufficient reduction of its temperature, may be frozen; and, under favourable circumstances, it assumes a regular crystalline form, a considerable degree of solidity or hardness, and a density exceeding that which it possessed in a fluid state. From the experiments of Mr. Keir, (Phil. Trans. lxxvii.) it follows that there is a certain point of specific gravity (*viz.* 1.780) at which the sulphuric acid most readily congeals; and, when of this degree of strength, it requires even a less degree of cold than is sufficient to freeze water, its congelation taking place at + 45° Fahrenheit. From the specific gravity of 1.786, on the one hand, to 1.775, on the other, it freezes at 32° Fahrenheit. It is singular that it remains congealed, at a temperature higher than that originally required for freezing it. Acid, for example, which did not become solid till its temperature was reduced to 32°, remained frozen at 45°. When of the specific gravity of 1.843, or as nearly as possible of that of commerce, it was found by Mr. Macnab to freeze at — 15° Fahrenheit; but this acid, mixed with rather more than half its weight of water, required for congelation the temperature of — 36° Fahrenheit. (Phil. Trans. lxxvi. 241.)

Rectification.—To purify sulphuric acid, it must be distilled in a glass retort, placed in the sand-bed of a reverberatory furnace. This process requires considerable care. But to those who have sufficient experience in chemical operations, the following instructions may be useful; especially as it is indispensable, in all experiments of research, to employ an acid purified by distillation.

The furnace, in which this process is conducted, should have a contrivance for supporting a sand-bath within it at a proper height, and an opening in the side, for transmitting the neck of the retort. (Pl. vii. figs. 62, 63.) The retort must be coated with clay and sand over its whole body, and also over that part of the neck which is exposed to the fire. It is then to be placed, the coating being previously dry, in the sand-bath, about one-half filled with sulphuric acid; and a receiver must be applied but not luted on. The fire must now be lighted, and raised with extreme caution. The first portion that comes over, amounting to about one-sixth, consists chiefly of water, and may be rejected. This is followed by the concentrated acid; and, at this period, there is great risk that the neck of the retort will be broken, by the contact of the condensed acid, which has a very high temperature, and which frequently cracks the glass, as effectually as the application of a red-hot piece of iron. The fire must be regulated by the register door of the ash-pit, so that several seconds may elapse between the fall of the drops into the receiver. The process may be continued as long as any acid is condensed. The retorts employed for this purpose should be most attentively annealed.

The difficulty of rectifying sulphuric acid is much diminished by using a retort of the capacity of from two to four quarts, when a pint of the acid is employed, and, by connecting its neck with the receiver by means of an adopter three or four feet long. The retort may be set over a charcoal fire, and the flame made to play gently on its bottom. No luting is to be employed, and the receiver is to be surrounded with cold water. With this arrangement, and a cautious regulation of the heat, Dr. Ure finds that sulphuric acid may be distilled without much risk, in a continuous gentle stream. (Quart. Jour. iv. 116.) The sudden explosions, that occasionally happen during the process, may be prevented either by putting into the retort a few sharp-pointed pieces of glass, or some slips of platinum, as recommended by Mr. Brande. (See also Faraday's Chemical Manipulation, sect. 409.)

Sulphuric acid may be less perfectly purified by diluting it with an equal weight of water, allowing the impurities to settle, decanting the clear liquor, and concentrating it to the proper degree in a glass retort. When purified, it is important, to its perfect preservation, to keep it in well stoppered bottles, and carefully to exclude all combustible matters, which decompose it and give it a dark colour.

Composition.—The following table exhibits the proportions of sulphur and oxygen, deduced from different experiments, in 100 parts of real sulphuric acid:

	Sulphur.	Oxygen.
From the experiments of Berthollet - - -	43.28 -	56.72
———————————— Klaproth - - -	42.20 -	57.80
———————————— Bucholz - - -	42.50 -	57.50
———————————— Berzelius - - -	39.92 -	60.08
Proportions admitted by Dr. Wollaston - -	40.0 -	60.0

If the proportions be taken at 40 sulphur and 60 oxygen, and if the acid consists, as Mr. Dalton supposes, of 1 atom of sulphur and 3 atoms of oxygen, the atom of sulphur will weigh 16; for as $(60 \div 3 =)$ 20 is to 40, so is 8 to 16. We may consider, then, the following numbers as representing the atomic weights of sulphur and sulphuric acid:

Weight of the atom of sulphur - - - - - - - -	16
Real sulphuric acid = 1 atom sulphur + 3 oxygen	40
Liquid sulphuric acid = real acid + 1 water - -	49

According to Gay Lussac, sulphuric acid is decomposed by heat alone, and is resolved into

Two volumes of sulphurous acid gas,
One volume of oxygen gas,

which, in sulphuric acid, supposing it gaseous, are condensed into two volumes.

Anhydrous Sulphuric Acid.

Besides the sulphuric acid already described, there is another kind, called, from the place where it has long been manufactured, the *Sulphuric Acid of Nordhausen.* It is prepared by distilling the dry proto-sulphate of iron, or the same salt, deprived of water by strong sulphuric acid. Gmelin has procured it during the rectification of common sulphuric acid, by changing the receiver at the moment when it is filled by opaque vapours, and surrounding the fresh receiver with ice. The anhydrous acid deposits itself on the inner surface of the receiver. (32 Ann. Ch. et Ph. 223.)

This acid is much used in dissolving indigo. It has been investigated by Dr. Thomson (System of Chemistry, 6th edit. ii. 113, and First Principles, i. 214,) and by M. Bussy. (Ann. of Phil. N. S. viii. 259, and Ann. de Ch. et de Ph. xxx. 23.) Its colour is always dark, and it is opaque. Its specific gravity is 1.896. When exposed to the air, it smokes, in consequence of its avidity for moisture. It boils at a temperature between 104° and 122° Fahr. When heated in a glass retort, to which a receiver is luted, surrounded by a mixture of snow and salt, one half of the acid passes over in a solid state, forming a snow-white substance, which resembles asbestus. This is *anhydrous sulphuric acid*, or real sulphuric acid free from water. In the retort there remains a liquid acid, consisting of 1 atom of acid and 1 atom of water, corresponding, therefore, with common oil of vitriol.

Anhydrous sulphuric acid smokes strongly on exposure to the air, and is dissipated so speedily, that it cannot be weighed. Dr. Thomson has obtained it crystallized in flat rhomboids, quite transparent, the large faces deviating very little from 90°. It liquefies at about 66° Fahr., and is then more fluid than common sulphuric acid, and has a high refractive power. At that temperature it has the specific gravity of 1.97. It dissolves sulphur, and acquires a fine blue colour, which, if more sulphur be added, is changed to green and brown. It also unites with selenium and with iodine. (37 Ann. de Ch. et Ph. 189.)

When the solid acid is dropped into water, it combines with that liquid so violently, as to make a noise resembling the quenching of a bar of red-hot iron. In the proportion of 2 atoms to 1 atom of water, it constitutes the Nordhausen acid, the atomic weight of which is, therefore, $80 + 9 = 89$. This acid, according to Bellani, has the specific gravity of 1.843, at 50° Fahr., and congeals at 53.6°. Exposed to the air, at nearly a freezing temperature, it yields crystals, which, when separated and liquefied, give a fluid of sp. gr. 1.78. It is condensed by freezing, and 1000 parts of density 1.78 become 925 parts of solid acid. (Quart. Journ. 2d series, iii. 224.)

Sulphurous Acid.

Sulphurous acid was discovered by Priestley. It may be formed, 1st, by burning sulphur at a low temperature in common air, under a glass bell; and if slips of linen cloth, dipped in a solution of potassa, be exposed to the vapour, the alkali forms a combination with the sulphurous acid, which may afterwards be washed off and evaporated. The dry salt, distilled with liquid tartaric acid, gives sulphurous acid gas. An improved apparatus for this distillation is described by Mr. Faraday. (Chem. Manip. sect. 415.)

2dly. It is formed exclusively when sulphur is burned in dry oxygen gas. The gas, when restored to its original temperature, is found to be contracted $\frac{1}{12}$th or $\frac{1}{18}$th of its bulk; but this is probably owing to the hydrogen contained in sulphur, for there is every reason to believe that oxygen gas, by becoming sulphurous acid, is not at all changed in volume.

3dly. By heating red oxide of mercury with one-fourth of its weight of sulphur, sulphurous acid is produced, in the proportion of about a cubic inch for every five grains of the oxide.

4thly. By boiling one part by weight of mercury with six or seven of sulphuric acid to dryness in a glass retort, and then raising the heat, sulphurous acid gas is formed, and may be collected and preserved over quicksilver. Half an ounce of mercury is sufficient for the production of several pints of the gas.

Its properties are the following:

It has a pungent and suffocating smell, exactly resembling that which arises when sulphur is burned in the open air.

Specific gravity.—It is more than twice as heavy as atmospherical air. One hundred cubic inches are stated by Mr. Kirwan to weigh 70.215 grains, which would make its specific gravity 2.265. By Sir H. Davy, the same volume is said to weigh 68 grains: this would give the specific gravity of 2.23, which agrees almost exactly with the statement of Thenard (i. 685.) According to a calculation of Dr. Thomson, founded on the proportion of its elements, its specific gravity should be 2.222. Berzelius finds it by experiment to be 2.247. (Ann. de Chim. et Phys. v. 178.)

Liquefaction.—Monge and Clouet long ago asserted, that if the gas be exposed, at the same time, to a temperature of 31° Fahrenheit, and to great pressure, it assumes a fluid state. Mr. Faraday, by producing it from mercury and concentrated sulphuric acid sealed up in a bent tube, obtained the sulphurous acid in a liquid state. He describes it as very limpid and fluid, and quite colourless. Its refractive power appeared to be nearly equal to that of water. It does not solidify at a temperature of 0° Fahr. When a tube containing it is opened, it does not rush out as with an explosion, but a portion of the liquid evaporates rapidly, cooling another portion so much as to leave the latter in a liquid state under common barometric pressure. It rapidly dissipates, however, without appearing in visible fumes, but with a strong odour of sulphurous acid, leaving the tube perfectly dry. A portion of the vapour collected over mercury proved to be pure sulphurous acid gas. A piece of ice, dropped into the fluid, instantly made it boil, from the heat communicated to it. The specific gravity of liquid sulphurous acid is about 1.42. At 45° Fahr. it exerts a pressure of about two atmospheres. (Phil. Trans. 1823, p. 190.)

M. Bussy, also, has produced *liquid anhydrous sulphurous acid* from a mixture of equal parts of mercury and sulphuric acid in a matrass. The gas was first passed into a vessel surrounded with powdered ice or snow, which condensed much of the moisture, and from thence was conveyed through a long tube, filled with recently fused chloride of calcium, into a small matrass surrounded by a freezing mixture of two parts ice or snow and one part of common salt. In this last vessel, the gas was condensed into a liquid under the ordinary pressure of the atmosphere.

The liquid anhydrous acid thus procured is colourless, transparent, of sp. gr. about 1.45, and boils at a temperature of 14° Fahr. It may easily, however, be preserved a considerable time; for the cold, produced by the volatilization of a part, lowers the temperature of the rest below its boiling point. It is exceedingly volatile, insomuch that mercury may be readily frozen in a thermometer tube by surrounding the ball with cotton wetted by the liquid acid. By its means, also, other gases may be liquefied under little additional pressure, as chlorine, ammonia, and cyanogen. (Ann. of Phil. N. S. viii. 307.)

Action on animals.—In a gaseous state, sulphurous acid extinguishes burning bodies, and, when respired, kills animals.

On silk.—It has the property of whitening or bleaching silk, and of giving it lustre, and removes fruit stains from woollen cloth.

Relation to water.—Of sulphurous acid, water absorbs 33 times its bulk, or one-eleventh of its weight, caloric is evolved, and the solution at 68° has the specific gravity 1.0513. Mr. Dalton states the quantity absorbed to be only 22 times the bulk of the water. From the solution, when recently prepared, the gas may be separated by heat, but not by congelation. The watery solution does not redden infusion of litmus, as acids in general do, but totally destroys its colour. Hence its use in bleaching several vegetable and animal substances. It restores the colour of syrup of violets, which has been reddened by other acids. (Nicholson's Journal, xvii. 303.)

Absorption by sulphuric acid.—Sulphuric acid, saturated with this gas, by passing the gas through the acid, acquires a strong smell, a yellowish brown colour, smokes when exposed to the air, and has the property of being rendered solid, by a moderate reduction of its temperature. When distilled, the first product, which is a compound of the two acids, assumes a solid form.

By borax.—Sulphurous acid is absorbed by crystallized borax, and by means of this property, first observed by Dr. Priestley, Cluzel observes, may be separated from carbonic acid and some other gases. (83 Ann. de Chim. 259.)

If sulphurous acid gas and fresh muriate of tin are brought into contact over mercury, the volume of the gas is speedily diminished, sulphur is deposited, and the proto-muriate becomes a per-muriate of tin. (Accum.)

It is decomposed when submitted to the heat of ignition, in contact with certain combustible bodies. Thus, when a mixture of sulphurous acid and hydrogen gases are driven through a red-hot porcelain tube, the oxygen of the acid combines with the hydrogen, and forms water, and sulphur is obtained in a separate form. The sulphurous acid is decomposed, also, when transmitted over red-hot charcoal; and, as appears from Gay Lussac's experiments, by potassium.

From the testimony of the same chemist, we learn that 100 parts of sulphur, to become sulphurous acid, unite with 95 by weight oxygen. The following Table shows the numbers derived from different authorities, Sulphurous acid contains per cent.

	Sulphur.		Oxygen.
According to Gay Lussac	51.30	- -	48.70
———— Berzelius -	50.03	- -	49.97
———— Thomson -	53.0	- -	47.0

The true quantities are probably equal weights of each element; and, as the relative weight of the atom of sulphur is double that of oxygen, sulphurous acid consists of

1 atom of sulphur	-	16
2 atoms of oxygen	-	16
		32

In volumes, it is constituted of

1 volume of vapour of sulphur } condensed into 1 volume.
1 volume of oxygen - - - - }

Oxygenation—Sulphurous acid is converted back to the state of sulphuric by restoring oxygen to it.

1. A mixture of oxygen and sulphurous acid gases, both perfectly dry, and standing over mercury, is not diminished by remaining in contact with each other during some months; but, if a small quantity of water be added, the mixture soon begins to diminish, and sulphuric acid is formed. Or if water impregnated with sulphurous acid be exposed to oxygen gas in a tube, the oxygen in 10 or 14 days is imbibed, and sulphuric acid formed. The same gases in a state of mixture afford sulphuric acid by the action of electricity, or by being driven through a red-hot porcelain tube. The proportions required for mutual saturation are two measures of sulphurous acid and one of oxygen gas.

2. When to a portion of water, saturated with sulphurous acid gas, a little per-oxide of manganese is added, the pungent smell of the water, and the other characteristics of sulphurous acid, will soon disappear.

3. Sulphurous acid gas is condensed into sulphuric acid by admixture with chlorine gas, provided the gases are in contact with water. In the latter case, the hydrogen of the water unites with the chlorine, and the oxygen with the sulphurous acid.

Action on nitrous gas.—Dry nitrous acid gas has no action on dry sulphurous acid; but, when placed in contact with a small quantity of water, all these bodies act mutually and rapidly on each other; the nitrous acid gas yields a portion of its oxygen to the sulphurous acid, from whence result hypo-nitrous acid and sulphuric acid, both of which, combining with water, form white flakes upon the inside of the balloon. These flakes are made up of congeries of small crystalline needles. Water, brought into contact with these crystals, dissolves the sulphuric acid, and nitrous gas is liberated with effervescence. By means, therefore, of a small quantity of nitrous gas, we may transform a large quantity of sulphurous acid into sulphuric acid, provided the acid gas be mingled with half its volume of oxygen, or with an equivalent quantity of atmospheric air. The phenomena are beautifully exhibited by admitting, into an exhausted and dry glass balloon, first 30 measures of sulphurous acid, next 15 of oxygen, and then 5 of nitrous gas. No perceptible change takes place till a little water is introduced, sufficient to moisten the inside of the vessel, when the small quantity of red nitrous acid, formed on adding the nitrous gas, disappears, and composes the crystalline substance already described. When these crystals have been deposited on the inside of the balloon, and a small quantity more of water is admitted, there is an immediate effervescence from the escape of nitrous gas, which, meeting with oxygen gas, again becomes nitrous acid, and this, acting upon the sulphurous acid, the same combinations ensue as before, and may be repeated as long as sufficient sulphurous acid and oxygen remain.

Theory of the production of sulphuric acid.—It is by a series of operations of this kind, that the formation of sulphuric acid is effected in the ordinary process for preparing it. The nitric acid, present in the saltpetre, abandons part of its oxygen to one portion of the sulphur, which, becoming sulphuric acid, unites with the potassa of the nitre. At the same moment nitrous gas is set at liberty, which, with the oxygen present in the air of the chamber, composes nitrous acid gas. Another portion of sulphur is converted into sulphurous acid, which becomes sulphuric acid by depriving the nitrous acid of oxygen, the latter acid being brought back to the state of nitrous gas. This gas, absorbing the atmospheric oxygen, again becomes nitrous acid, which changes a fresh portion of sulphurous into sulphuric acid. This theory was first suggested by MM. Clément and Desormes. It has been since modified by Gay Lussac, who supposes that nitrous acid, and not nitrous gas, is disengaged from nitrate of potassa. But, even if this be admitted, the subsequent steps of the process are still explicable on the original theory, which satisfactorily explains why so small a proportion of nitre as one-eighth is adequate to the conversion of sulphur into sulphuric acid, though capable of supplying only a very small share of the oxygen essential to this change.

Of Hypo-sulphurous Acid.

This acid, like the hypo-nitrous, exists only in combination with salifiable bases, forming compounds which were first examined in 1813 by Gay Lussac, and were called by him *sulphureted sulphites.* Beside other methods of preparing these salts, he found that they might be obtained by digesting the solution of a sulphite with sulphur, an additional quantity of which might thus be made to combine with the sulphurous acid. It had also been long ago observed by Mr. Higgins of Dublin, that liquid sulphurous acid dissolves iron without effervescence; and Berthollet afterwards showed that in this case the iron is oxidized at the expense of the sulphurous acid, and that sulphur is disengaged, which immediately unites with the sulphite of iron, forming a sulphureted sulphite.

Dr. Thomson appears to have been the first who took a just view of these phenomena. (Syst. of Chem. 5th edition.) The new compound he found to be a neutral salt, containing a peculiar acid of sulphur, to which he gave the name of *hypo-sulphurous acid,* and to its compounds that of *hypo-sulphites.*

These compounds have been since examined with great ability by Mr. Herschell (Edin. Phil. Journ. i. 8 and 36), who has not, however, succeeded in his attempt to exhibit the acid in a separate state; nor indeed does it appear capable of existing permanently when uncombined with a base. From the experiments of Mr. Herschell, as well as from his own, Dr. Thomson formerly inferred it to be a compound of 1 atom of sulphur + 1 atom of oxygen, and its representative number to be 16 + 8, = 24. He has since, however, in an essay on chromium (published in the Phil. Trans. for 1826), deduced the composition of hypo-sulphurous acid to be 2 atoms of sulphur (32) + 1 atom of oxygen (8) together 40; but its precise constitution cannot yet be considered as sufficiently established. Its properties will again come under review in speaking of the several hypo-sulphites.

Hypo-sulphuric Acid.

This acid was discovered by Welter and Gay Lussac. Their process for forming it consists in passing a current of sulphurous acid through water, in which finely powdered peroxide of manganese is kept mechanically suspended. There is immediately produced a perfectly neutral solution, consisting of hypo-sulphate and common sulphate of manganese. When the solution is sufficiently concentrated, pure baryta is added to the previously heated liquor, and agitated along with it, taking care to employ an excess of the earth. All the oxide of manganese is thus separated; and, sulphate of baryta being insoluble, the filtered liquor contains only the hypo-sulphate and the redundant baryta. The latter is to be separated by a stream of carbonic acid, and subsequent ebullition to expel any excess of carbonic acid. The hypo-sulphate of baryta is then to be crystallized, dissolved in water, and decomposed by just the quantity of sulphuric acid, which is required to precipitate the baryta. The filtered liquor is to be concentrated, by exposing it under the exhausted receiver of an air-pump, along with a shallow vessel of sulphuric acid, till it has attained the density of 1.347. If continued to be exposed, it is resolved into sulphurous acid which exhales, and sulphuric acid which remains liquid. Heeren advises that when sulphurous acid is passed over black oxide of manganese, the oxide should be finely divided and the temperature low. The largest portion of the hypo-sulphuric acid is formed at the commencement of the process. (Ann. de Chim. et de Phys. x. 312. See also Heeren, Quart. Journ. New Ser. ii. 473.)

Oxygen gas, atmospheric air, chlorine, concentrated nitric acid, and red sulphate of manganese, are all inert on it at common temperatures. Zinc is dissolved by it, and hydrogen gas is disengaged by the decomposition of water, and there remains in solution hypo-sulphuric acid combined with oxide of zinc. It completely saturates salifiable bases, and affords neutral and soluble compounds with baryta, strontia, lime, and protoxide of lead; whereas sulphuric acid yields insoluble compounds with all those bases. At common temperatures these salts are permanent, but, when heated, sulphurous acid escapes, and they pass to the state of sulphates, which are still neutral.

Hypo-sulphuric acid has been inferred to be composed of 100 parts of sulphur + 125 oxygen, setting apart that which is in the water essential to its existence; or we may consider it as a compound of 100 parts of sulphurous acid + 125 of sulphuric. Hence we have the four following acids with base of sulphur.

	Vols. of	Atoms of	
	Sul. Oxy.	Sul. Oxy.	At. Wt.
1. Hypo-sulphurous acid	1 + 0.5	1 + 1	24
2. Sulphurous acid	1 + 1.	1 + 2	32
3. Sulphuric acid	1 + 1.5	1 + 3	40
4. Hypo-sulphuric	2 + 2.5	2 + 5	72

ART. 2.—*Sulphur with Chlorine.*

Sulphur, when heated in contact with chlorine gas, or even when exposed to it at common temperatures, absorbs it, and forms a singular compound, first described by Dr. Thomson (Nicholson's Journal, 8vo. vol. vi.), and afterwards investigated by Berthollet, jun. (Mem. d'Arcueil, tom. i.) Ten grains absorb almost 30 cubic inches of gas, which is nearly in the proportion of 16 (the weight of an atom of sulphur) to 36 (the weight of an atom of chlorine). It appears, indeed, to be a true binary compound or *chloride of sulphur*, and its atomic weight is 16 + 36 = 52.

This fluid is volatile below 200° Fahrenheit. Its colour is red by reflected light, but yellowish green by transmitted light. It emits fumes, which are peculiarly acrid, and which excite a copious flow of tears. Its specific gravity is 1.6. When agitated with about an equal volume of water, an active ebullition and great disengagement of heat take place; sulphur is deposited; and the residuary liquid contains muriatic and sulphurous, and a small quantity of sulphuric, acids. Hence the water is decomposed, and while its hydrogen unites with the chlorine, its oxygen combines with the greater part of the sulphur. Alcohol and ether are decomposed with appearances of still more intense action, and it disunites also the elements of ammonia.

Mercury acts strongly upon this liquid; its surface is first tarnished, great heat is evolved, and a grey powder is formed, which is a mixture of sulphur and chloride of mercury.

It reddens vegetable blue colours; but not till, by its action on water or on hydrogen, muriatic acid has been produced. Some chemists have considered it as an acid, and have proposed to call it the *chloro-sulphuric acid;* but besides being deficient in the other qualities of acids, it does not, like true acids, unite with salifiable bases, and form peculiar salts.

Sulphur with Iodine.

Sulphur and iodine unite at a gentle heat, and a black radiated compound is formed, resembling sulphuret of antimony. It is easily decomposed at a degree of heat a little above that at which it was produced, and iodine is detached from it in vapour. Its precise composition is unknown.

SECTION VII.

Of Selenium.

In the chambers for manufacturing sulphuric acid from the sulphur which is procured at Fahlun in Sweden, a reddish mass is deposited, which is principally sulphur. This substance, in burning, gives out an odour, which induced Berzelius to suspect that it contained tellurium, but on a minute examination he discovered, in 1818, instead of that metal, a body with entirely new properties, to which he has applied the name of *selenium*. The process, by which it was extracted, is described in the 13th vol. of Annals of Philosophy, p. 403; but as the source of it is extremely rare, it will be sufficient to refer to Berzelius's description; and to the improved method of M. Lewenau in the 8th vol. of the N. S. of the same work. It has since been discovered in the volcanic rocks of Lipari; in several varieties of sulphur; and in sulphuric acid made with pyrites obtained from the isle of Anglesea. (Annals of Phil. N. S. vols. viii. and ix.) Its separation from sulphur Berzelius easily effects by fusing the compound with carbonate of potassa, not in excess. When water is added to the fused mass, the selenium only is left undissolved. (Phil. Mag. and Ann. Phil. Nov. 1827, p. 390.) Selenium has also been discovered by M. Henry Rose in several minerals from the Eastern Harz, united with lead, cobalt, copper, and mercury, (Ann. de Ch. et de Ph. xxix. 113,) and Stromeyer and Haussman have analyzed a seleniuret of lead from the Laurence mine at Clausthal. (Ann. of Phil. N. S. x. 233.)

The colour of selenium varies a good deal. When rapidly cooled, its surface has a dark brown hue, and its fracture the colour of lead. Its powder has a deep red colour, but it sticks together when pounded, and then assumes a grey colour and a smooth surface. It softens at 212° Fahr., and completely fuses at a few degrees higher. While cooling, it has a considerable degree of ductility, and may be kneaded between the fingers, and drawn out into fine threads, which have a strong metallic lustre, an imperfect degree of transparency; and are red by transmitted, but grey by reflected light. When slowly cooled, it assumes a granulated fracture, and is extremely like a piece of cobalt. At a temperature nearly equal to that of boiling mercury, selenium enters into ebullition; and condenses, either into opaque metallic drops, or, when a retort with a large neck is used, into flowers of a fine cinnabar colour. Its vapour has a deep yellow colour, more intense than that of chlorine, but not so deep as that of sulphur. When heated before the blow-pipe, it tinges the flame of a fine azure blue, and exhales so strong a smell of horse-radish, that a fragment, not exceeding $\frac{1}{50}$ of a grain, is sufficient to fill the air of a large apartment.

Selenium and oxygen.—Oxide of selenium is formed by heating selenium in a close phial with common air, which acquires a very strong smell of horse-radish. Water agitated with this air imbibes the odour of the gas, and reddens litmus feebly, but this appears to be owing to the production of a small quantity of selenic acid. Selenic oxide gas is very sparingly soluble in water, and does not impart any taste to it. It does not combine with liquid alkalies. Its precise composition is unknown; but it appears to belong to the same class of oxides as carbonic oxide.

Selenious acid.—Selenium dissolves in nitric and nitro-muriatic acids, and when the solution is evaporated in a retort, so as to expel the excess of those acids, there remains a white saline mass, which sublimes on raising the temperature, and forms a vapour, the colour of which closely resembles that of chlorine. In the cold part of the apparatus, selenious acid condenses in very long four-sided needles. These crystals, when first taken out of the retort, have a dry aspect and a peculiar lustre. Exposed to the air, they adhere to each other, and the lustre becomes dull, but they do not liquefy.

Selenious acid has a sour taste, and leaves a slightly burning sensation on the tongue. It is very soluble in cold water, and dissolves in almost every proportion in boiling water. A saturated solution crystallizes, when rapidly cooled, in small grains, and when slowly cooled in striated prisms. The crystals dissolve in great abundance in alcohol, and the solution, when distilled, yields a fluid having an ethereal smell.

Selenious acid unites with most bases in two proportions, and with some in three, and forms a class of salts called *Selenites* or Biselenites, &c., which will be described with their respective bases.

Selenious acid is easily reduced both in the moist and the dry way. When a plate of zinc or polished iron is introduced into a solution of selenious acid mixed with muriatic acid, selenium is precipitated in the form of red, or brown, or blackish flakes. It is revived, also, by sulphureted hydrogen and sulphurous acid gases.

From his investigation of this acid, Berzelius considered it as selenium united with the maximum proportion of oxygen, and has inferred it to consist of

Selenium	71.261	100.00
Oxygen	28.739	40.33
	100.	

On the supposition that it is constituted of an atom of base + 2 atoms of oxygen, the equivalent number for selenium will be 40, and for selenic acid 56. The same atomic weight for selenium is deducible also from the proportion in which it unites with hydrogen.

Selenic acid.—The acid, which has just been described, was considered by its discoverer Berzelius as the *selenic*, but this name is more properly applied to a compound of selenium with oxygen, first observed by Mitscherlich, containing an additional proportion of the latter element. (Ann. de Ch. et de Ph. Sept. 1827.) It is prepared by fusing nitrate of potassa with selenium, with selenious acid, or with a seleniuret, such as that of lead, freed from earthy impurities by muriatic acid. The residue, amounting to about one-third of the whole, is mixed with an equal weight of nitrate of soda, and projected, by a little at once, into a red-hot crucible. The lead is oxidized, and the selenium is converted into selenic acid, which combines with the soda. The purification of the seleniate of soda, thus prepared, involves many details, for which I refer to the memoir above quoted. The last step of the process consists in decomposing seleniate of lead in solution, by sulphureted hydrogen, which precipitates sulphuret of lead, leaving the selenic acid in such a state as to be purified by ebullition.

Composition.—The neutral salts which selenic acid forms with bases, being isomorphous with those containing sulphuric acid, indicates a similarity of constitution between the two acids, and chemical investigation proved that, for the same quantity of base, the oxygen of the selenic acid is, as in the sulphuric, three times that of the base; in other words, that selenic acid is composed of 1 atom of selenium and 3 atoms of oxygen.

Selenic acid is a colourless liquid, which may be heated to 536° Fahr. without sensible decomposition, but at 554° is resolved into oxygen and selenious acid. Its specific gravity, freed as completely as possible from water, is 2.625; but, even when of this density, it still contains 15.75 of water in 100 of acid. Like sulphuric acid, it evolves great heat when suddenly diluted. When heated with muriatic acid, it affords chlorine and selenious acid, and like aqua regia dissolves gold. Selenic acid dissolves iron and zinc with a disengagement of hydrogen, copper with an evolution of selenious acid, and gold, but not platinum.

In its affinities for bases it is a little inferior to sulphuric acid, but its compounds (seleniate of baryta for instance) are not entirely decomposed by the latter acid.

Selenium and chlorine.—Selenium absorbs chlorine gas, and becomes hot and forms a brown liquid, which, by an additional quantity of chlorine, is converted into a white solid mass. This is stated by Berzelius to be a compound of muriatic and selenic acids, but it is probably composed of chloride of selenium and selenious acid. It has not yet been accurately separated into its component parts, for when heat is applied, both substances are sublimed.

The remaining compounds of selenium will be described hereafter in their proper places. At present, it is only necessary to observe farther, that while this body possesses some of the characters of metals, (the metallic lustre for example,) it is destitute of others that are essential to its arrangement in that class. It has more transparency than any metal, and is distinguished, also, from the metals, by the want of power to conduct electricity or heat. In some respects it resembles tellurium; but, on the whole, its properties are most analogous to those of sulphur; and it may be regarded as forming the connecting link between the non-metallic combustibles and the metals.

CHAPTER VIII.

OF THE COMBINATION OF SIMPLE ACIDIFIABLE BODIES (NOT METALLIC) WITH EACH OTHER.

SECTION I.

Hydrogen with Nitrogen.—Ammonia.

Art. 1.—*Preparation and Qualities of Ammonia.*

I. Ammonia, in a liquid form, had been long known to chemists, both Basil Valentine and Raymond Lully having described the methods of procuring it from animal substances. Priestley, and, more recently, Chevallier discovered it in native oxides of iron, thus establishing its presence in the mineral kingdom. An important step in its chemical history had been previously made by Dr. Black, who first distinguished between its pure or caustic, and its mild or carbonated state, and Dr. Priestley first exhibited it in a gaseous form, to which he gave the name of *alkaline air*. To procure it in this state, one of the following processes may be employed.

1. Mix together equal parts of muriate of ammonia and dry quicklime, each separately powdered; and introduce them into a small gas bottle or retort. Apply the heat of a lamp, and receive the gas, that is liberated, over mercury.

2. To a saturated solution of ammonia in water, or the pure liquid ammonia, in a gas bottle, apply the heat of a lamp; and collect the gas, as in *a*.

II. This gas has the following properties:

It has a strong and very pungent smell.

It immediately extinguishes flame; and is fatal to animals. Before, however, a candle is extinguished, by immersion in this gas, the flame is enlarged, by the addition of another, of a pale yellow colour, which descends from the mouth to the bottom of the jar. If the flame of the candle be only in part surrounded with the gas, this yellowish flame rises a few lines above the other.

It is lighter than atmospheric air. Hence a jar filled with this gas, and placed with its mouth upwards, is soon found to exchange its contents for common air, which, by its greater specific gravity, descends, and displaces the ammoniacal gas. By the experiments of Messrs. Allen and Pepys, undertaken at the desire of Sir H. Davy, 100 cubic inches of ammonia were found to weigh 18.18 grains, barometer 30, thermometer 60°. (Phil. Trans. 1808.) According to Gay Lussac, its specific gravity is to that of common air as 0.5967 to 1; and hence (taking 100 cubic inches of air at 30.5 grains) 100 cubic inches of ammonia weigh 18.17 grains. It does not appear that in any of these trials, the gas was artificially dried. To effect its desiccation, potassa or quicklime are best adapted; for dry chloride of lime, as well as several other chlorides, absorb it rapidly. (Quart. Journ. v. 74.) Calculating from the proportion of its elements and their state of condensation, its true specific gravity ought to be 0.59027, for this number results from adding together the specific gravity of nitrogen gas, and three times the specific gravity of hydrogen gas, and dividing the sum by 2.

It has been asserted by Guyton, that ammoniacal gas is reduced to a liquid state at 70° below 0 of Fahrenheit; but it may be questioned whether the drops of liquid, which he observed, were any thing more than a watery vapour, which the gas always contains, condensed by the cold, and saturated with ammonia. (Ann. de Chim. xxix. 290.) Mr. Faraday has exhibited it in a liquid form, by disengaging it in sealed tubes from chloride of silver, which had been made to absorb it. Liquid ammonia, thus obtained, was colourless, transparent, and very fluid. Its refractive power surpassed that of water itself. At 50° Fahr. the pressure of its vapour was equal to about 6.5 atmospheres. Its specific gravity was 0.76. (Phil. Trans. 1823, p. 196.)

Ammoniacal gas is not sufficiently inflammable to burn when in contact with common air. But, when expelled from the extremity of a pipe, having a small aperture surrounded by oxygen gas, I have found that it may be kindled, and it then burns with a pale yellow flame, the products of its combustion being water and nitrogen gas.

Ammoniacal gas may be decomposed by transmitting it through a red-hot porcelain tube, which should be either well glazed internally, or covered externally with a lute. It has been ascertained by Thenard (85 Ann. de Ch. 61), that when any of the five following metals are enclosed in the tube, they promote the decomposition of ammonia at a temperature much below that which it would require *per se*, in the order set down, *viz.*, iron, copper, silver, gold, and platinum; iron being most effectual, and platinum least. Iron, after the process, is found to be rendered brittle, and copper still more so. The gas obtained always consists of 3 parts hydrogen by measure, and 1 nitrogen. None of the metals is either increased or diminished in weight; and they can only, therefore, act as conductors of heat. Yet it is singular that iron decomposes a much larger quantity than platinum, and at a lower temperature.

M. Savart, who has recently repeated these experiments, with great care, and with ammoniacal gas deprived of moisture, finds that copper wire does, however, gain a very slight increase of weight, not exceeding 1-275th; its properties are altered as generally described, and its specific gravity diminished from 8.865 to 7.791. A cylinder of iron, used to decompose ammonia, during nine hours, gained only 1-670th of its weight, and the iron acquired some of the properties of steel. No gas was liberated by fusing the altered copper in a porcelain retort. M. Savart is of opinion that these facts support the opinion that azote is the oxide of a base, called provisionally ammonium, which, by alloying with the copper and other metals, causes the change of their properties. (Ann. de Ch. et de Ph. xxxvii.)

Ammonia is rapidly absorbed by water. A drop or two of water being admitted to a jarful of this gas, confined over mercury, the gas will be immediately absorbed, and the mercury will rise, so as to fill the whole of the jar, provided the gas be sufficiently pure. Ice produces the same effect, in a still more remarkable manner. From Sir H. Davy's early experiments, it appeared that 100 grains of water absorb 34 grains of ammoniacal gas, or 190 cubic inches. Therefore a cubic inch of water takes up 475 cubic inches of the gas. More recently he has stated that at 50° Fahrenheit, water absorbs 670 times its bulk, and acquires the specific gravity .875. (El. of Ch. Phil. p. 263.) Even this is much below the proportion absorbed in Dr. Thomson's experiments, *viz.*, 780 volumes of ammoniacal gas by 1 vol. of water.

Alcohol, also, absorbs several times its bulk, and affords a solution of ammonia, which possesses the strong smell, and other properties, of the gas.

Water, by saturation with this gas, acquires its peculiar smell; and constitutes what has been called liquid ammonia; or, more properly, solution of pure ammonia in water. The method of effecting this impregnation is as follows:

Process for obtaining Solution of Ammonia in Water.

The following process is given by Mr. R. Phillips, as preferable to that of the London Pharmacopœia. (Remarks on the London Pharm. p. 34.)

On 9 oz. of well-burnt lime, pour half a pint of water, and when it has remained in a well-closed vessel for nearly an hour, add 12 ounces of muriate of ammonia, and about 3½ pints of boiling water. When the mixture has cooled, filter the solution; and, having put it into a retort, distil off 20 fluid ounces. The solution will have the specific gravity 0.954, which is quite as strong as it can be conveniently kept. If the solution be required to be more strongly impregnated, this will be best effected by passing ammoniacal gas through it, from a mixture of equal parts of powdered lime and muriate of ammonia, by means of an apparatus similar to that described for the preparation of muriatic acid. In the Quart. Journ. (for July 1828, p. 477) a process of Sig. Bizio is described, by which, from every pound of muriate of ammonia, 1.61 of a pound of liquid ammonia may be obtained of sp. gr. 0.910.

The strength of a solution of ammonia is influenced by two circumstances, the temperature of the liquid, and the pressure on its surface; for ammonia is not retained in water without external force. The intervals of temperature, required to double the force of ammoniacal vapour, were ascertained by Mr. Dalton to increase in ascending. When mixed with common air, its elasticity is not altered; thus when ammoniacal gas of 15 inches force is mixed with a given volume of dry air, the air is doubled in bulk.

Solutions of ammonia, when mixed with water, were found by

Sir H. Davy, not to be sensibly condensed; and, therefore, if the quantity of ammonia in a solution of given specific gravity be determined, it is easy to calculate the quantity in solutions of other densities. The two following Tables, it may be observed, do not exactly agree in their results, the quantity of ammonia, in solutions of the same density, being from 15 to 20 per cent. less in Mr. Dalton's Table than in Sir H. Davy's. The numbers in the latter, marked with an asterisk, were found by experiment, and from these the others were deduced.

Sir H. Davy's Table of the Quantities of Ammoniacal Gas in Solutions of different Densities. (Temp. 50° Fahrenheit, Barometer, 29.8.)

100 parts of Specific Gravity.		Of Ammonia.	100 parts of Specific Gravity.		Of Ammonia.
.8750*	contain	32.5	.9435	contain	14.53
.8875		29.25	.9476		13.46
.9000		26.	.9513		12.40
.9054*		25.37	.9545		11.56
.9166		22.07	.9573		10.82
.9255		19.54	.9597		10.17
.9326		17.52	.9619		9.60
.9385		15.88	.9692*		9.50

Mr. Dalton's Table of the Quantities of Ammonia in Solutions of different Specific Gravities.

Specific Gravity.	Grains of Ammonia in 100 water-grain measures of liquid.	Grains of Ammonia in 100 grains of liquid.	Boiling point of the liquid in degrees of Fahrenheit.	Volumes of gas condensed in a given volume of liquid.
850	30	35.3	26°	494
860	28	32.6	38°	456
870	26	29.9	50°	419
880	24	27.3	62°	382
890	22	24.7	74°	346
900	20	22.2	86°	311
910	18	19.8	98°	277
920	16	17.4	110°	244
930	14	15.1	122°	211
940	12	12.8	134°	180
950	10	10.5	146°	147
960	8	8.3	158°	116
970	6	6.2	173°	87
980	4	4.1	187°	57
990	2	2.	196°	28

ART. 2.—*Analysis of Ammonia.*

(1) Ammoniacal gas is decomposed by electricity; and its bulk, as Dr. Priestley first observed, is thus gradually enlarged. Into a glass tube, having a conductor sealed hermetically into one end (fig. 29), and standing inverted over mercury, pass about one-tenth of a cubic inch of ammoniacal gas; and transmit through it a succession of electrical discharges from a Leyden jar. The arrangement of the apparatus for this purpose is shown in fig. 84, pl. ix. When two or three hundred discharges have been passed, the gas will be found to have increased to twice its original bulk, and to have lost its property of being absorbed by water. Mix it with a quantity of oxygen gas, equal to between one-third and one-half of its bulk, and pass an electric spark through the mixture. An explosion will immediately happen; and the quantity of gas will be considerably diminished. Note the amount of the diminution; divide it by 3; and multiply the product by 2. The result shows the quantity of hydrogen gas in the mixed gases which have been generated by electricity; for two measures of hydrogen are saturated by one of oxygen gas.

Suppose, for example, that we expand 100 measures of ammonia to 200; and that, after adding 80 measures of oxygen gas, we find the whole (= 280 measures) reduced by firing to 55 measures; the diminution will be 225. Dividing 225 by 3 we have 75, which multiplied by 2 gives 150 measures of hydrogen gas from 100 of ammonia. Deducting 150 from 200, we have 50 for the nitrogen gas contained in the product of electrization. Therefore 100 measures of ammonia have been destroyed, and expanded into

150 measures of hydrogen gas, = 3 volumes.
50 ———— nitrogen gas, = 1 volume.

To ascertain the precise amount of the gases evolved from ammonia, great care and nicety are necessary; for if either the gas itself, or the mercury which confines it, contain any moisture, the product of gas, resulting from its decomposition, will exceed what it ought to be. The problem is one of importance, because from the proportion of the elements of ammonia, is deduced the weight of the atom of nitrogen. This will differ considerably, according to the statement, which we may adopt, of the amount of gases obtained by decomposing ammonia; their proportion to each other, and the exact specific gravities of hydrogen and nitrogen gases. I have, therefore, again analyzed ammonia with every possible precaution to avoid sources of inaccuracy, and have obtained results strictly agreeing with the proportions above stated. (Ann. of Phil. N. S. viii. 341). If then hydrogen be made the decimal unit, and it be admitted that the 3 volumes of hydrogen in ammonia represent 3 atoms, and the 1 volume of nitrogen 1 atom, the weights of the atoms of hydrogen and nitrogen will be as their specific gravities, *viz.*, as .0694 to decimal point .9722, or as 1 to 14. Ammonia, according to this view, will be constituted of three atoms of hydrogen = 3 + 1 atom of nitrogen = 14, and its representative number will be 17.

(2) In the Philosophical Transactions for 1809, I have described a property of ammonia, which forms the basis of a very easy and quick mode of analyzing that alkali. When mingled with oxygen gas, it may be inflamed by the electric spark, precisely like a mixture of hydrogen and oxygen gases. To obtain accurate results, however, it is necessary to use less oxygen at first than is sufficient to saturate the whole hydrogen of the alkali; for, if the full proportion of oxygen be employed, part of the nitrogen also is condensed into nitric acid. In the first combustion of 100 volumes of ammonia, we may use, therefore, 50 measures of oxygen, which will be entirely consumed. To the residue, we may add 30 or 35 measures more, and inflame the mixture by an electric spark, noting the diminution. Of this diminution, one-third is oxygen, and adding it to the oxygen spent in the first combustion, we have the whole oxygen consumed. This, being doubled, shows the volumes of hydrogen in 100 of ammonia, which will generally prove to be 150. The nitrogen may be learned by deducting, from that found by trial in the residue, the quantity introduced as an impurity of the oxygen, and it will be found that when the process has been carefully performed, the remainder amounts to 50 volumes.

(3) *Chlorine and ammonia.*—Scheele first observed that when liquid solutions of chlorine and ammonia are mixed, or when aëriform chlorine is passed through liquid ammonia, nitrogen gas is disengaged, and muriatic acid formed. In this case the hydrogen of the ammonia unites with the chlorine, and the nitrogen is liberated. The latter process furnishes a method of obtaining nitrogen gas; but, as thus procured, the gas has an odour, indicating the presence of a small quantity of chloride of nitrogen.

If into a bottle containing two or three pints of chlorine gas, about a drachm of strong solution of ammonia be poured, the two gases, when diffused through each other, act with sufficient energy to cause a detonation. The impossibility of confining chlorine gas, either by water or mercury, renders its decomposing action on ammonia of little use as a means of analyzing that compound; but Dr. Thomson has successfully employed the dichloride of lime to decompose the ammonia existing in common sal ammoniac, and, by particular management, obtains the whole of its nitrogen in a gaseous state. (First Princ. i. 129.)

The results of the analysis of ammonia furnish a good example of the condensation of the elements of gases, which takes place on chemical union; and if we could, by any means, permanently condense a mixture of three volumes of hydrogen and one of nitrogen into two volumes, the new gas would constitute ammonia. Simple admixture of these gases, even in the same proportions which are obtained by analyzing ammonia, is not sufficient to generate this alkali; for the caloric, with which the hydrogen and nitrogen are respectively combined, by its elasticity opposes their union, and places them beyond the sphere of their mutual attractions. If these elements are presented to each other when one or both are deprived of part of their caloric, combination then takes place; and the composition of the volatile alkali is proved synthetically, as in the following experiments.

(1) When iron filings, moistened with water, are exposed to nitrogen gas confined over mercury, the gas, after some time has elapsed, acquires the smell of volatile alkali. (Austin in Phil. Trans. vol. lxxviii.) In this case, the iron decomposes the water, and seizes its oxygen; while the hydrogen, at the moment of its liberation, unites with nitrogen, and composes ammonia. This state of condensation, or absence of the quantity of caloric necessary to bring it into a gaseous form, has been called the nascent state of hydrogen gas; and the same term has been applied to the bases of other gases when in a similar state. Priestley observed a production of ammonia by exposing iron to nitrous gas, and by acting on iron with nitrate of copper.

(2) Another fact, showing the mutual relation of ammonia and of the compounds of nitrogen, was discovered many years ago, by Mr. Higgins of Dublin. (See his Comparative View of the Phlogistic and Antiphlogistic Theories, 2d edit. p. 300, note.) Moisten some powdered tin (which is sold under that name by the druggists) with strong nitric acid; and, when the red fumes have ceased to arise, add some quicklime or solution of pure potassa. A strong smell of ammonia will be immediately produced. In this experiment, the tin attracts, at the same instant, the oxygen both of the nitric acid and of the water. Hydrogen and nitrogen are consequently set at liberty; and, before they have assumed the gaseous state, these two bases combine, and constitute ammonia. The ammonia thus generated unites with a portion of undecomposed nitric acid; and is disengaged from this combination by potassa or lime, which render it evident to the smell.

(3) A similar production of ammonia has been shown by Mr. R. Phillips to take place, when nitric acid is acted upon by phosphorus, which, simultaneously decomposing both water and nitric acid, enables the hydrogen of the former, and the oxygen of the latter, to unite while in a nascent form. It is produced, also, when heat is employed to dissolve silver in concentrated nitric acid. (Ann. de Ch. et de Phys. xxiv. 295.)

ART. 3.—*Salts with Base of Ammonia.*

Salts with base of ammonia, with the exception of a few which are decomposed at a high temperature into their ultimate elements, are capable of being raised by sublimation. They all give ammoniacal gas when heated with pure alkalies or earths; and their solutions are rendered acid by exposure to the atmosphere, in consequence of the escape of a portion of their base.

Chlorine and ammonia.—No compound of chlorine and ammonia can exist; for as soon as ammonia is brought into contact with chlorine, it is decomposed in the manner which has been already described.

Chlorate of ammonia may be formed either by saturating carbonate of ammonia with chloric acid, or by precipitating the solution of any earthy chlorate by that carbonate. Chlorate of ammonia forms fine needle-shaped crystals, which are extremely soluble in water and in alcohol. It is volatile, and, when thrown upon a red-hot coal, detonates with a red flame. The proportion of its components is not known. (See Vauquelin, Ann. de Chim. xcv. 97.)

Iodine and ammonia.—Dry ammoniacal gas is absorbed by iodine without decomposition. The product is at first very viscid, and has a metallic aspect; but by an excess of ammonia it loses these properties, and becomes of a very deep brownish red. When iodine is added to liquid ammonia, one part of it unites with the hydrogen of the alkali, and forms hydriodic acid, while another portion of the iodine combines with the azote, and falls down in the form of a black powder. This compound of iodine and azote detonates with a very gentle heat, and even with the slightest touch.

Iodate of ammonia.—This salt is best formed by saturating iodic acid with ammonia. It is deposited in small crystalline grains of an indeterminate form. When these are thrown on a red-hot coal, they detonate with a feeble violet flame and an escape of iodine. When heated in close tubes, the tubes are frequently burst; but Gay Lussac succeeded in collecting the products, which were equal volumes of oxygen and azotic gases. He states its composition at 100 acid + 10.94 ammonia, or 2 volumes of gaseous ammonia, 1 volume of iodine in vapour, and 2½ volumes of oxygen.

Hydriodate of ammonia is constituted of equal volumes of hydriodic acid gas and ammoniacal gas. It may be formed by mixing the watery solutions of the acid and base. It crystallizes in cubes which are more soluble than sal ammoniac, and nearly as volatile, subliming in close vessels without decomposition.

Hydro-chlorate, or Muriate, of Ammonia.

Muriate of ammonia may be formed by mixing over mercury equal measures of ammoniacal gas and muriatic acid gas, which are entirely condensed into a white solid. This is the only proportion in which the two gases unite. For purposes of experiment, the common sal ammoniac of the shops is sufficient, which is prepared by a circuitous process from an impure carbonate of ammonia, obtained by the distillation of bones, and other animal matters. This carbonate of ammonia, by being kept in contact with sulphate of lime and water, is converted into sulphate of ammonia. This again is decomposed by muriate of soda, which affords muriate of ammonia and sulphate of soda. The latter salt is separated by priority of crystallization, and the muriate of ammonia is then purified by being once or twice sublimed.

It has been ascertained by Dr. Marcet, that muriate of ammonia exists in sea water, and may be separated by sublimation from the uncrystallizable part called *bittern.* (Phil. Trans. 1822, p. 454.)

It is easy to calculate the composition of this salt, for since 100 cubic inches of muriatic acid gas weigh 39 grains, and the same volume of ammonia weighs 18.18 grains, muriate of ammonia, recently sublimed, or dried for some time on a sand-bath, must consist of

		Atom.	
Muriatic acid	68.519	1	37
Ammonia	31.481	1	17
	100.		54

In its ordinary state, the salt contains water, the proportion of which, according to Berzelius, is 19 parts in 100 of the salt (80 Ann. de Chim. 253); but this does not agree with any atomic constitution, and it is probable, therefore, that the water is not essential to it, but accidental.

Muriate of ammonia exhibits the following properties:

It is volatilized, without being liquefied or decomposed, or, in other words, may be *sublimed*. Sir H. Davy finds that it may even be passed, without alteration, through glass or porcelain tubes heated to redness. When, however, it is transmitted over ignited metals, it is decomposed into its gaseous elements.

It is readily soluble in water, three parts and a half of which, at 60°, take up one of the salt. During its solution, much caloric is absorbed. In boiling water it is still more soluble; and the solution, on cooling, shoots into regular crystals.

It slightly attracts moisture from the air.

On the addition of a solution of pure potassa, or pure soda, the alkali is disengaged, as is evinced by the pungent smell that arises on the mixture of these two bodies, though perfectly inodorous when separate.

Though generally considered as a neutral salt, yet, if placed on litmus paper and moistened, Berzelius observes, that the paper is reddened after some moments, as it would be by an acid.

It is decomposed by baryta, strontia, lime, and magnesia.

Nitrate of Ammonia.

The most simple mode of preparing this salt is by adding carbonate of ammonia to dilute nitric acid, till saturation has taken place. If the liquor be evaporated, by a heat between 70° and 100°, to a certain extent, it shoots, on cooling, into crystals, having the shape of six-sided prisms, terminated by long six-sided pyramids. Evaporated at the temperature of 212°, it yields, on cooling, thin fibrous crystals; and, when the evaporation is carried so far that the salt immediately concretes on a glass rod by cooling, it then forms a compact and shapeless mass.

The solubility of this salt varies, according to the temperature in which it has been formed. When in crystals, it requires twice its weight of water for solution, or half its weight of boiling water. It deliquiates, in all its forms, when exposed to the atmosphere.

The most important property of this salt is the one which has been already described, *viz.* of yielding, when decomposed by heat, the nitrous oxide. One pound of the compact kind gives, by careful decomposition, nearly five cubic feet of gas, or rather more than

34 doses; so that the expense, estimating the salt at 5*s.* 10*d.* the pound, is about 2*d.* for each dose.

In a temperature of 600° this salt explodes, and is entirely decomposed. Hence it was formerly called *nitrum flammans.*

Its composition varies according to the mode of its preparation, and is stated by Sir H. Davy as follows:

	Prismatic.	Fibrous.	Compact.
Acid	69.5	72.5	74.5
Base	18.4	19.3	19.8
Water	12.1	8.2	5.7
	100.	100.	100.

The prismatic variety is stated by Berzelius, (80 Ann. de Chim. 182,) who investigated very carefully the results of its decomposition, to consist of

		Atom.	
Acid	67.625	1	54
Base	21.143	1	17
Water	11.232	1	9
	100.		80

Carbonates of Ammonia.

Carbonate of ammonia consists of 1 volume of carbonic acid and 2 volumes of ammonia, which, when mingled over mercury in that proportion, undergo complete condensation. As 100 cubic inches of carbonic acid weigh 46.56 grains, and 200 of ammonia 36.36 grains, in all 82.92 grains, carbonate of ammonia must consist of

		Atom.	
Carbonic acid	56.20	1	22
Ammonia	43.80	1	17
	100.		39

These proportions differ very little from the experimental results of Gay Lussac (56.02 acid + 43.98 base).

Bi-carbonate of ammonia was formed by Berthollet, by impregnating a solution of the common carbonate with carbonic acid gas. It crystallizes, when evaporated by a very gentle heat, in small six-sided prisms, has no smell, and but little taste. It consists, according to Berthollet, exclusive of water, of

		Atoms.	
Carbonic acid	71.81	2	44
Ammonia	28.19	1	17
	100.		61

Sesqui-carbonate of ammonia.—Besides these two compounds of ammonia and carbonic acid, there is another which is generally met with in the shops, under the name of *sub-carbonate of ammonia.* It is produced by exposing to heat, in a proper subliming apparatus, a mixture of 1 part muriate of ammonia and 1½ of dry carbonate of lime, and, if no loss occurred during the operation, it ought to consist of 1 atom of carbonic acid, 1 of ammonia, and 1 of water. But the heat, which is necessary to the decomposition, expels both ammonia and carbonic acid, and the resulting salt has the following proportions:

	Acid.	Base.	Water.
According to Dr. Ure[*]	54.5	30.5	15.
Mr. Phillips[†]	54.2	29.3	16.5

The atomic constitution, nearest the above proportions, and that which probably belongs to the salt in its perfect state, is as follows:

		Atoms.	
Acid	55.72	3	66
Base	29.	2	34
Water	15.28	2	18
	100.		118

Viewing it as a compound of 1½ proportions of carbonic acid, 1 ammonia, and 1 of water, it has been called by Mr. Phillips a *sesqui-carbonate*, and, if this view be unconnected with the notion of its containing the fraction of an atom, there can be no objection to the name. It is preferable, indeed, to that of sub-carbonate, which should be reserved for the compound, hitherto unknown, of 1 atom of acid and 2 of base.

When the sesqui-carbonate is fresh prepared, it has a crystalline appearance and some transparency, and is hard and compact. It has a pungent smell, and a sharp penetrating taste, and affects vegetable blues as uncombined alkalies do. It dissolves in twice its weight of cold, or an equal weight of boiling water; but at the latter temperature it gives off part of its acid. When exposed to the atmosphere, it loses weight very fast, ceases to be transparent, and becomes inodorous and brittle, and easily reducible to powder. When its chemical composition is now examined, it is found to be identical with the bi-carbonate, or to consist of

Two atoms of acid	44
One atom of base	17
Two atoms of water	18
	79

It has therefore lost, by exposure to the air, 1 atom of acid and 1 atom of base.

By varying the proportions of the ingredients, and the regulation of the heat, it is possible to obtain a bi-carbonate at once by sublimation. (Annals of Phil. N. S. iii. 110.)

Borate of ammonia, formed by saturating boracic acid with ammonia, crystallizes somewhat like borax. When heated, part of the base is expelled. It consists, according to Berzelius, of

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[*] Annals of Phil. x. 206.

[†] Quarterly Journal, vii. 294.

Acid	37.95	100.
Ammonia	30.32	79.895
Water	31.73	
	100.	

Arfwedson has described three varieties of borate of ammonia, for an account of which I refer the reader to the Ann. of Phil. 2d series, x. 125.

Phosphite of ammonia is a very soluble salt, and is with difficulty brought to crystallize.

Hypophosphite of ammonia is very soluble both in water and alcohol. Its composition has not been ascertained.

Phosphate of ammonia may be formed by saturating the superphosphate of lime, resulting from the action of sulphuric acid on bones, with carbonate of ammonia. The liquid, when evaporated spontaneously, crystallizes in low four-sided pyramids with square bases. It is soluble in twice its weight of water at 55° Fahr. When heated, it fuses, swells, and, if the heat be strongly urged, loses its alkaline base, the phosphoric acid being left in a glacial form.

Sulphite of ammonia crystallizes in six-sided prisms, terminated by six-sided pyramids. It is soluble in an equal weight of cold, or in less than an equal weight of boiling water. It attracts moisture from the air, and rapidly passes to the state of a sulphate. It is constituted of 100 acid + 53.2 base, or of an atom of each of its elements; and the crystals consist of 2 atoms of salt and 1 atom of water; but they may also be obtained anhydrous. (Phil. Mag. and Ann. of Phil. Nov. 1827.)

Hyposulphite of ammonia.—According to Mr. Herschell, this is strictly a bi-salt, consisting of 2 atoms of acid and 1 of base. It does not readily crystallize. Its taste is pungent and excessively bitter. When heated, it burns with a feeble flame, and evaporates.

Sulphate of ammonia may be formed by uniting 100 parts of the compact sesqui-carbonate, with 88 of sulphuric acid, previously diluted with water. The salt crystallizes in long flattened prisms with six sides, terminated by six-sided pyramids. These crystals have a cool bitter taste; they slightly attract moisture from the air; are soluble in two parts of water at 60°, or in an equal weight of boiling water. During solution they produce cold. When heated, they sublime; but the constitution of the salt undergoes some change.

It is composed, according to Berzelius, of

		Atoms.	
Sulphuric acid	53.1	1	40
Ammonia	22.6	1	17
Water	24.3	2	18
	100.		75

When dried as much as possible without decomposing it, Dr. Ure found that it lost an atom of water, or that it consisted of 61 acid + 25.96 ammonia, + 13.04 water.

Selenites of ammonia.—Selenious acid (selenic of Berzelius) unites with ammonia in three different proportions, forming selenite, biselenite, and quadriselenite. These salts, which are not important, are described by Berzelius, under the name of seleniates, now due only to the compounds of the new acid of Mitscherlich with bases. (Ann. de Chim. et Phys. ix. 260.)

SECTION II.

Combinations of Hydrogen with Carbon.

The aëriform compounds of hydrogen with carbon cannot be obtained by heating charcoal in hydrogen gas, for the cohesive attraction of the particles of charcoal effectually prevents combination. It may be accomplished, however, by exposing to a high temperature some of the solid and liquid compounds of hydrogen and charcoal, of which there are several; and it is produced also by some natural operations, especially by animal and vegetable putrefaction.

Until lately, only two distinct and well characterized compounds of carbon and hydrogen had been so well investigated, as fully to satisfy us of their properties, and the proportions of their elements. The first is called simply *carbureted hydrogen*, or *bi-hydruret of carbon;* and the second is most commonly known by the name of *olefiant* gas. Besides these, a third has been pointed out by Mr. Dalton, as entering into the composition of oil and coal gas, to which he proposes that the name of *super-olefiant* should be provisionally given; and Mr. Faraday, in the Philosophical Transactions for 1825, has still further enlarged our knowledge of these compounds, by bringing us acquainted with at least two others. The following Table exhibits a general view of these gases, the fourth and fifth being those discovered by Mr. Faraday. I omit the compound of 1 atom of carbon + 1 atom of hydrogen, as not yet sufficiently made out by experiment.

Table of the Gaseous Compounds of Carbon and Hydrogen.

		Each volume		Each vol. contains vols. of		Proportions by weight.	Atoms of
	Sp. Gr.	consumes Oxyg.	gives Car. Ac.	Carb.	Hyd.	Car. Hyd.	Car. Hyd.
1. Bi-hydruret of carbon -	0.555	2 vol.	1 vol.	1 vol.	2 vol.	6 : 2	1 + 2
2. Olefiant gas -	0.972	3 vol.	2 vol.	2 vol.	2 vol.	12 : 2	2 + 2
3. Super-olefiant	1.458?	4.5 vol.	3 vol.	3 vol.	3 vol.	18 : 3	3 + 3
4. New gas - -	1.9943	6 vol.	4 vol.	4 vol.	4 vol	24 : 4	4 + 4
5. Bi-carb. hyd.	2.7082	7.5 vol.	6 vol.	6 vol.	3 vol.	36 : 3	6 + 3

In the second, third, and fourth compounds, it may be observed that carbon and hydrogen are present in the same relative proportions to each other; and, in their constitution, these gases, therefore, can only differ in the state of condensation of their elements. In olefiant gas, 2 volumes of gaseous carbon, and 2 volumes of hydrogen, occupy the space of 1 volume; in super-olefiant, we have 3 volumes of each element condensed into 1 volume; and, in Mr. Faraday's new gas, we have 4 volumes of each in the space of one volume. It is probable that, besides these, other aëriform compounds of carbon and hydrogen exist. We may expect, for instance, to become acquainted with a compound of 1 volume of carbon and 1 volume of hydrogen condensed into 1 volume. Of such a compound we can anticipate the specific gravity by adding the sp. gr. of gaseous carbon .4166 to that of hydrogen .0694, making 0.4860, and can estimate, from obvious data, that each volume must consume 1.5 vol. of oxygen, and give 1 volume of carbonic acid. It is remarkable that this compound of an atom of each element has not yet been met with in nature, or been produced in a distinct form by art, though, on theoretical grounds, it might have been expected to be the one which would be most readily and frequently formed. Dr. Thomson has proposed for it the name of *carbo-hydrogen*, and has described a compound gas, which he believes to be constituted of an atom of carbo-hydrogen and an atom and a half of chlorine.

By the destructive distillation of solid and liquid compounds of carbon and hydrogen, it is seldom that we obtain any one of these gases separately, but in most cases a mixture of two or more. Hence there is an almost infinite variety in the specific gravity and composition of gases thus obtained, which gave occasion to the opinion that charcoal and hydrogen are capable of combining *in every proportion*. There can be no doubt, however, that these apparently numerous compounds are mixtures of a few; and that combinations of charcoal and hydrogen take place *in definite proportions* only, with this peculiarity, that they differ from each other not so much in the *relative proportions* of their elements, as in the *numbers of volumes or atoms condensed into a given volume*.

ART. 1.—*Carbureted Hydrogen Gas.*

This gas has been distinguished also by the name of *heavy inflammable air, gas of marshes, hydro-carburet, proto-carburet of hydrogen*, and has been termed, by Dr. Thomson, *bi-hydroguret*, abbreviated by others into *bi-hydruret, of carbon*.

It may be obtained, mixed, however, with about $\frac{1}{20}$ of carbonic acid, and $\frac{1}{15}$ or $\frac{1}{20}$ of nitrogen gas, by stirring the bottom of almost any stagnant pool of water, especially if formed of clay. When this is done by an assistant, the gas is copiously disengaged in bubbles, which may be collected either in an inverted glass jar, or in an inverted bottle filled with water, into the mouth of which a funnel is fixed. It should be washed, when collected, with lime water or liquid potassa.

It may also be procured by the purification of gas from coal, by means of chlorine and solution of potassa, applied in succession, in a manner which will afterwards be described in speaking of coal gas.

Carbureted hydrogen, thus obtained, is permanent over water, which, after being well purged of air by boiling, is capable of taking up about $\frac{1}{61}$th of its bulk. It has very little odour, the strong and disagreeable smell of coal gas being dependent on foreign admixtures. Its specific gravity, from Dr. Thomson's experiments and my own, is 0.555; and hence 100 cubic inches, at a mean of the barometer and thermometer, weigh 16.95 grains.

When set on fire as it issues from a small orifice, it burns with a yellow flame, giving out vastly more light than hydrogen gas. When mixed with atmospheric air, it may be kindled by a lighted taper, and it explodes with violence, provided it forms not less than $\frac{1}{12}$th of the mixture, and does not exceed $\frac{1}{6}$th. With oxygen gas, the detonation is louder and more violent; but it is necessary that the oxygen should rather exceed the inflammable gas in volume, and yet should not be more than $2\frac{1}{4}$ times its bulk. Under a pressure diminished below $\frac{1}{4}$th that of the atmosphere, the mixture ceases to be combustible; and its inflammability is also much lessened by mingling it with carbonic acid and some other gases. To burn it completely in close vessels over water or mercury, it is necessary to use more than twice its volume of oxygen gas, of which exactly two volumes are consumed, and carbonic acid is produced, equivalent in volume to the inflammable gas. Now we know that in carbonic acid gas there exists exactly its volume of oxygen; and hence one volume of the oxygen spent is found in that compound, and the other volume has formed water with the hydrogen, which last element must have existed in quantity equivalent to twice the bulk of the inflammable gas. The water produced may be collected by the slow combustion of the gas, but this is not necessary for calculating the proportion of its elements, which may be correctly stated as follows:

One volume contains	2 vols. hydrogen -	0.1388
	1 vol. carbon - - -	0.4166
	Specific gravity -	0.5554

By weight it consists of	2 atoms of hydrogen	2
	1 atom of carbon - -	6
	Atomic weight -	8

When carbureted hydrogen and chlorine gases are mixed together, no change happens either immediately or on standing, provided light be carefully excluded; but, if exposed to the ordinary light of day, and still more rapidly in sunshine, a mutual action ensues. If 4 volumes of chlorine, and 1 of carbureted hydrogen, be thus kept, during a few hours, in a bottle filled entirely with the mixture, and furnished with a well-ground stopper, on removing this under water, a sudden absorption of muriatic acid gas takes place, and 1 volume of carbonic acid remains. Three volumes of chlorine and 1 of carbureted hydrogen afford a residue of carbonic oxide. In both cases, water is decomposed (for the gases do not act at all on each other if perfectly dry), the oxygen of the water uniting with the carbon, and its hydrogen with the chlorine. If the quantities be sufficiently large, and the sun's rays fall on the mixture, a detonation ensues, which may also be produced either by an electric spark, or by a lighted taper.

Art. 2.—*Olefiant Gas.*

This gas was discovered by the associated Dutch chemists, and was termed by them *olefiant gas*, from a property which will presently be described. It has since been called *bi-carbureted* or *per-carbureted hydrogen*, and by Dr. Thomson *hydroguret of carbon*; but, to avoid all ambiguity, I shall continue to use its original name, which has never been applied to any other substance. It may readily be obtained by distilling, in a glass retort, with a gentle heat, three measures of concentrated sulphuric acid, and one measure of alcohol. The mixture soon assumes a black colour and thick consistence, and a gas is disengaged which may be collected over water, and freed from carbonic acid by washing it with liquid potassa. If left to stand long over water, it sustains a diminution, that fluid being capable of taking up ⅛th of its volume of the gas.

Olefiant gas, when pure, has very little odour, except when mingled with a little sulphuric ether, which is formed along with it. Its specific gravity is stated by the Dutch chemists at .909; by my experiments, made several years ago, it is .967; by those of Saussure, jun., .9852; and, by Dr. Thomson's latest trials, 0.9709. According to the last-mentioned result, 100 cubic inches, at a mean of the barometer and thermometer, weigh 29.64 grains.

Olefiant gas, when set on fire as it issues from the orifice of a small pipe, burns with a remarkably dense and bright flame, very superior to that of simple carbureted hydrogen. When mingled with oxygen gas, it detonates very loudly and forcibly, and if fired by electricity in a Volta's eudiometer, is apt, unless very small quantities be employed, to burst the instrument. One volume requires 3 volumes of pure oxygen gas, and affords 2 volumes of carbonic acid gas. But, in order to ensure the perfect combustion of the inflammable gas, it should be mixed with 5 times its bulk of oxygen, of at least 90 per cent. purity. If too little oxygen be used, charcoal is apt to be precipitated unburned; and a small excess of oxygen does no harm, but remains in the mixture. When fired with less than its own bulk of oxygen, the separation of charcoal is very evident, and the bulk of the residue is greater than that of the original gases.

Calculating the constitution of this gas, from the oxygen spent in its combustion and the carbonic acid formed, precisely as was done with respect to carbureted hydrogen, we have the following results:

In each volume	2 vols. of hydrogen - -	0.1388
	2 ditto of carbon - - -	0.8332
	Specific gravity	0.9720

The compound atom consists of	2 atoms of hydrogen -	2
	2 atoms of carbon - -	12
	Atomic weight -	14

Its greater combustibility evidently depends on its containing in a given volume twice the quantity of carbonaceous matter, that is present in simple carbureted hydrogen.

When chlorine gas is added to olefiant gas over water, an immediate diminution ensues; and this effect takes place even when the vessel is shaded from the light by an opaque cover. It is therefore wholly independent of the agency of light, and may be made the basis of a method of analyzing a mixture of olefiant and carbureted hydrogen gases. For of the diminution thus produced, one half is due to the olefiant, and one half to the chlorine gas, those gases having been ascertained to saturate each other in equal volumes. Into a graduated tube standing over water admit 30 or 40 measures of chlorine gas, and note its bulk when actually in the tube, which must be shaded by an opaque cover. Then add a known quantity (suppose 50 measures) of the gas under examination; and, after ten minutes, cautiously lift the outer cover, till the surface of the water appears. If the volume of the two gases has suffered no diminution, we may infer the absence of olefiant gas; but, if the united bulk of the two gases be less than the sum of their separate volumes, divide the diminution by 2, and the quotient will show how much olefiant gas has been condensed. In this way I have found that olefiant and carbureted hydrogen gases may be accurately separated from each other; but it is necessary to use a slight excess of chlorine, which may afterwards be removed by washing the residue with liquid potassa, and the carbureted hydrogen will then be obtained pure. The exclusion of light is necessary in this experiment, to avoid the risk of an explosion, which has been observed to happen, a dense deposit of charcoal at the same time filling the receiver. (Ann. of Phil. 2d ser. xii. 312.)

By the action of chlorine gas, a liquid substance is formed, in appearance very much resembling oil, and which, being at first mistaken for oil, occasioned this gas to be called *olefiant*. It possesses, however, very different properties from those of oil, and more nearly approaches in character to ether. It may be collected in quantity by mixing large volumes of chlorine and olefiant gases, taking care to have an excess of the latter; and it may be purified by washing it with water, and then distilling it from dry chloride of calcium. It has an agreeable ethereal smell, and a not unpleasant taste. Its specific gravity at 45° F. is 1.2201; it boils at 152°; and its vapour is capable of supporting a column of mercury 24.66 inches in height, and the specific gravity of its vapour is to that of air as 3.4434 to 1. It consists of 1 vol. of chlorine + 1 vol. of olefiant gas condensed into 1 vol. or by weight of

Chlorine -	72.5 - -	1 atom -	36
Olefiant gas -	27.5	1 atom -	14
	100.	Atomic weight	50

When olefiant gas is mixed with eight or nine times its bulk of *chlorine*, and exposed to the sun's rays, at first the fluid hydrochloride of carbon is formed, and this, by continuing the exposure, is changed into the crystalline compound of carbon and chlorine, discovered by Mr. Faraday, and already described as the *perchloride of carbon.*

Hydriodide of carbon.—When *iodine* and olefiant gas are exposed in a similar manner to the sun's rays, the two substances unite, and form colourless crystals. When the redundant iodine has been washed away by liquid potassa, and the residue collected and dried, it is a solid white crystalline body, heavier than sulphuric acid; having a sweet taste and an aromatic smell; friable, and a non-conductor of electricity; fusible, and capable of being sublimed at a moderate heat without change; but decomposed by a strong heat. It is not readily combustible, but, when held in the flame of a spirit lamp, burns, diminishing the flame, and giving off abundance of iodine and some fumes of hydriodic acid. It is insoluble in water, and in acid and alkaline solutions; but dissolves in alcohol and in ether. It may be termed *hydriodide of carbon, or hydro-carburet of iodine.* (Faraday, Phil. Trans. 1821.) From an analysis by Mr. Faraday, it appears to consist of 1 atom of iodine + 2 atoms of olefiant gas. (Quarterly Journal, xiii. 429, and Mitscherlich, Ann. de Ch. et de Ph. xxxvii. 85.)

Hydro-bromide of carbon.—Olefiant gas and *bromine* were found, by M. Balard, to act upon each other. A drop of bromine, introduced into a flask full of the gas, absorbs it, and assumes the appearance of an oily fluid, heavier than water, and of a sweet etherial flavour. It is not, however, like hydro-chloride of carbon, convertible into a bromide of carbon, by further exposure in olefiant gas to sunlight. It is produced, also, by distilling the mother liquor of salt pans, through which chlorine has been passed. M. Serullas, who has pursued the investigation of its formation and properties, finds that it is best obtained by bringing 2 parts of bromine into contact with 1 of hydriodide of carbon; the products being bromide of iodine, and *hydro-bromide of carbon.* At 23° to 25° Fahr. the latter compound becomes solid, and then resembles camphor. (Ann. de Ch. et Phys. xxxiv. 95.)

ART. 3.—*Of Super-Olefiant Gas.*

The name of *super-olefiant* has been given by Mr. Dalton, provisionally, to a gas not yet exhibited in a separate form, but mingled with others in the aëriform products of coal, oil, &c. In the Philosophical Transactions for 1821, p. 156, I have given an account of the discovery of this gas by Mr. Dalton, and stated circumstances which leave little room for doubt of its existence as a distinct species. One volume requires for complete combustion, according to my experiments, 4½ volumes of oxygen, and gives 3 vols. of carbonic acid. Its specific gravity, as near as I could approximate, is 1.4, but if constituted, as seems probable, of 3 volumes of gaseous carbon and 3 volumes of hydrogen condensed into 1 volume, its specific gravity should be

Sp. gr. of hydrogen .0694 × 3 = 0.2082
Sp. gr. of carbon - .4166 × 3 = 1.2498

Estimated sp. gr. 1.4580

That it is a permanent gas, and not a vapour, I ascertained by subjecting a portion of oil gas, of which it formed more than 40 per cent., to the temperature produced by a mixture of snow and muriate of lime, which did not liquefy any appreciable portion of it. Like olefiant gas, it is condensable by chlorine, but the product has a peculiar smell, differing from that of chloric ether, and, I have reason to believe, consists, partly at least, of a compound of chlorine and carbon.

Art. 4.—*New Compounds of Carbon and Hydrogen, discovered by Mr. Faraday.*

When oil gas (see art. 5,) is subjected, in proper vessels, to a pressure of about 30 atmospheres, a fluid is deposited in the proportion of nearly a gallon from 1000 cubic feet, which may be drawn off, and preserved in glass bottles of ordinary strength. It is a thin light fluid, sometimes transparent and colourless, at others opalescent, being yellow or brown by transmitted, and green by reflected light. It has the odour of oil gas. Its specific gravity is 0.821. It does not solidify at a temperature of 0 Fahr. It is, in fact, a mixture of various fluids, which, though they resemble each other in being combustible, and in throwing off much smoke when burnt in large flame, may, by their difference of volatility, be separated in part from each other.

A portion of the liquid, distilled by the heat of the hand, gave about thrice its volume of uncondensed vapour, and was separated into a fluid which boiled more easily, and another which boiled less easily, than the original one. In taking the products successively at every 10° Fahr. it was observed that the boiling point was more constant at or between 176° and 190° than at other temperatures, large quantities of fluid then distilling over without any change of the degree of heat; whereas, in other parts of the series, it was constantly rising. Rejecting what came over under 170° Fahr., the subsequent products were received separately at every 10° up to 200° or 210°. These were again rectified, and the products between 175° and 195° collected apart from the rest, and subjected to a cold of 0 Fahr. by means of a freezing mixture. Crystals were thus deposited, in the midst of a fluid, from which they were separated by bibulous paper introduced into the tube, and then by strong pressure between folds of bibulous paper cooled to 0 Fahr. The substance thus obtained was distilled from caustic lime, to separate any water that might still adhere to it.

Though a solid at low temperatures, yet, in common circumstances, this compound appears as a colourless transparent liquid, having the odour of oil gas. Its specific gravity is about 0.85 at 60°. When cooled to about 32° it becomes solid, but fuses again when raised nearly to 42° Fahr., thus agreeing with water, which, as is well known, may be cooled several degrees below its freezing point, without being changed into ice. During congelation, 9 parts in bulk contract to 8 very nearly; hence its specific gravity is about 0.956. At 0° Fahr. it is a white or transparent solid, brittle, pulverulent, and of the hardness nearly of loaf sugar.

When exposed to the air, it entirely evaporates. Its boiling point in a glass vessel is 186°. The specific gravity of its vapour, corrected to the temperature of 60° Fahr. is nearly 40, hydrogen being 1. It is slightly soluble in water, but very soluble in fixed and volatile oils, in ether, alcohol, &c.; the alcoholic solution is precipitated by water. It is decomposed by being transmitted through a red-hot tube, depositing carbon, and yielding carbureted hydrogen gas. It is very combustible, burning with a dense smoke if not well supplied with air, but otherwise burning with extreme brightness. When admitted to oxygen gas, so much vapour arises as to make a powerfully detonating mixture. It enters into union with chlorine, and affords both a solid and fluid, both of which are triple compounds of carbon, chlorine, and hydrogen, in different proportions.

The action of sulphuric acid on this compound is very remarkable, the combination taking place without heat, with no blackening of the acid, and with no formation of sulphurous acid. The acid thus combined forms, with bases, a peculiar class of salts.

By analysis over ignited peroxide of copper, the gas or vapour was proved to consist of so nearly 12 parts by weight of carbon and 1 of hydrogen, that we may consider it as a *bi-carburet of hydrogen*, constituted of

Carbon - - 2 atoms - 6 × 2 = 12
Hydrogen - - 1 atom - - - - - 1

Atomic weight - 13

For its combustion, 1 volume of the vapour requires 7.5 volumes of oxygen, 6 of which combine with carbon to form 6 of carbonic acid, and the remaining 1.5 combine with 3 of hydrogen to form water. The hydrogen present in 1 volume is equivalent, therefore, to 3 volumes, and the carbon to 6 volumes; or a volume of the substance in vapour contains

Carbon - - 6 × 6 = 36
Hydrogen - 1 × 3 = 3

39

and its weight or specific gravity will, of course, be 39, hydrogen being 1.

The portion, incondensable from the rectified fluid by a cold of 0° Fahr., when separated from the crystalline solid, boiled at 186°. In its general characters of solubility, combustibility, non-action of potassium, &c., it agreed with the substance already described. Its sp. gr. was 0.86 at 60°. Sulphuric acid acted upon it much more powerfully than upon the bi-carburet, and was thickened and blackened. By analysis, it gave

Carbon - -	8.764
Hydrogen -	1

But, as it must necessarily have contained much bi-carburet of hydrogen, it is evident that if in a pure state, the proportion of carbon would fall much below the above, and would probably be as 6 only to 1, constituting a simple *carburet* of *hydrogen*, or true binary compound, containing an atom *of each element.*

New Carburet of Hydrogen.

This was obtained from the original fluid by distilling it with the heat of the hand, and condensing what came over by a cold of 0° Fahr. The condensed liquid boiled by a very slight increase of temperature, and was resolved into a gas permanent over mercury at common temperatures. This gas, being cooled to 0°, again condensed into a liquid, which, when examined in a tube hermetically sealed, had the sp. gr. 0.627 at 54°: it is therefore the lightest fluid known.

The gas or vapour at 60° Fahr. has the sp. gr. 27 or 28, hydrogen being 1. When agitated with water, it is absorbed in small quantities. Alcohol absorbs it, and a solution is obtained, from which much of the gas is disengaged by the addition of water. Olive oil dissolves about six times its volume; one volume of sulphuric acid condenses above 100 volumes of the vapour, with the evolution of great heat; the acid is much blackened; and, on dilution, becomes turbid, but gives out no gas.

One volume of the vapour consumes 6 volumes of oxygen, of which 4 are spent in forming carbonic acid, and 2 in producing water. On this view 4 volumes of hydrogen (= 4) are combined with 4 volumes of carbon (= 24) to form 1 volume of the combustible gas, the specific gravity of which should therefore be 28, agreeing very nearly with the result of experiment.

Chlorine and this gas or vapour combine in nearly equal volumes, producing a liquid *hydro-chloride* of *carbon*, which must contain twice as much hydrogen and carbon as the liquid obtained by the similar treatment of olefiant gas. This liquid, exposed to chlorine in sun-light, absorbs a further portion, but no chloride of carbon is produced. This is a remarkable circumstance, and concurs, with other facts, to show that, though the elements of the new gas or vapour are the same, both in kind and in proportion, as those of olefiant gas, yet that they are in a very different state of combination.

It has been remarked by Mr. Faraday, that the phenomena exhibited by oil gas, which led Mr. Dalton to infer the existence of super-olefiant gas as one of its constituents, may be equally well explained on the supposition that oil gas consists of mixtures of previously known gases with the 4th and 5th of the table (page 360), and probably with others as yet undefined. It must be acknowledged that the third gas of the table still remains to be established as a distinct species, though there appears to me sufficient reason to believe, from analogy, that it forms one of the series. From the experiments of Mr. Faraday it may be deduced that no more volatile substance is present in oil gas than the one (No. 4 of the Table) requiring a pressure of 4 atmospheres at 60° Fahr.

All the vapours or gases, which are denser than olefiant gas, it was found, may be separated from that gas and from bi-hydruret of carbon, with considerable exactness, by sulphuric acid or oil. Sulphuric acid introduced over mercury absorbs them instantly, evolving no sulphurous acid, and not acting on olefiant gas, except after a contact of some hours. In this way, good oil gas lost 22 or 23 per cent.; oil gas, after compression into Gordon's portable lamps, lost 17 or 18 per cent.; and coal gas, of poor quality, lost about 3½ per cent. Oil may be used in a similar manner for the separation of these vapours, of which it condenses about 6 times its volume at common temperatures.

The fluid obtained from compressed oil gas, it has been suggested, may be advantageously applied to improving the quality of any gas which burns with a feeble flame. It is also an excellent solvent of caoutchouc, and of those substances which are the bases of varnishes, to the composition of which it is well adapted by its great volatility. (See Mr. Faraday's Memoir, Phil. Trans. 1825.)

ART. 5.—*On the mixed Combustible Gases from moist Charcoal, Alcohol, Ether, Coal, Oil, Tallow, and Wax.*

The gases, which have been described in the four preceding articles, appear to me to be the only aëriform compounds of carbon and hydrogen that have as yet been proved to be distinct and well characterized species. It is of mixtures of two or more of those gases, with occasionally a proportion of carbonic oxide and a few others, that the almost infinite variety of aëriform products are constituted, which are obtainable by the exposure of moistened charcoal, of alcohol or ether, of oil, tallow, wax, resin, or coal, to a heat a little above ignition.

Of these aëriform compounds, the gases from coal and from oil are of most importance, from their widely extended use in artificial illumination.

Coal Gas.—By submitting coal to distillation in an iron retort, besides a portion of tar and solution of carbonate of ammonia, which condense in a liquid form, a large quantity of permanent gas is evolved. This gas I have shown (Phil. Trans. 1808 and 1820) is extremely variable in composition and properties, not only when prepared from different coals, but from the same kind of coal under different circumstances. Within certain limits, the more quickly the heat is applied, the greater is the quantity, and the better the quality, of the gas obtained from coal; for too slow a heat expels the inflammable matter in the form of tar. The early products of gas are, also, the heaviest and most combustible, and there is a gradual decline in quality towards the close of the distillation, insomuch that the last products are inferior, by more than one half, to the first. The general name of *coal gas* is, therefore, quite indefinite. It is, most probably, a mixture of the first four varieties of carbureted hydrogen with hydrogen gas, carbonic oxide, carbonic acid, nitrogen, and sulphureted hydrogen gases, in ever-varying proportions. To describe the methods of separating these gases from each other, would lead me at present into too minute details, and I refer therefore to the papers which I have published in the Phil. Trans. for 1808, 1820, and 1824, and in the 3d. vol., 2d Series, of the Manchester Society's Memoirs, or in the Annals of Philosophy, vol. xv. An abstract of the analytical part of those papers will be found in chapter xiv. sect. 1, of the second volume of this work.

Coal gas, as generally procured, has a very disagreeable odour, arising from sulphureted hydrogen, and, perhaps, a little sulphuret of carbon; but both these may be washed out of it by cream of lime, with (as I have shown) very little loss of illuminating power, and with an entire removal of all unpleasant smell either before or during burning. The best gas has the specific gravity .650 or upwards; and each volume consumes about 2¼ volumes of oxygen, and gives 1¼ volume of carbonic acid; the last portions have a specific gravity as low as .340, and each volume consumes about 8-10ths of a volume of oxygen, and gives about 3-10ths of a volume of carbonic acid. In the best gas, chlorine, applied as directed page 364, detects from 13 to 20 per cent. of olefiant gas, and the remainder is almost pure carbureted hydrogen; but the last products contain little or no olefiant gas, much less carbureted hydrogen, and, instead of these, a large proportion of hydrogen and carbonic oxide, both of which yield very little light by their combustion.

It is scarcely possible to assign the quantity of gas, which ought to be obtained from a given weight of coal, but it may be considered as an approach to a general average to state that 112lb. of good coal are capable of giving from 450 to 500 cubic feet of gas of such quality, that half a cubic foot per hour is equivalent to a mould candle of six to the pound, burning during the same space of time.

Oil Gas.—In Nicholson's Journal for 1805, I have given an account of some experiments on the gas obtained by the destructive distillation of sperm. oil, which showed that of all the artificial gases, this, next to olefiant gas, consumes most oxygen, and is the best adapted to afford light. Since that time, an apparatus has been invented by Messrs. Taylor, of London, which has greatly facilitated the preparation of oil gas on a large scale, and this gas is now much used as a source of artificial light. The process consists in letting whale oil (the purity of which is not essential, since inferior oil answers the purpose) fall by drops into an iron cylinder placed horizontally in a furnace and ignited to a cherry redness. From each wine gallon of oil, about 100 cubic feet of gas may with care be obtained, of the specific gravity of more than .900, containing upwards of 40 per cent. of gas condensable by chlorine, and of which 100 volumes consume 260 volumes of oxygen, and yield 158 of carbonic acid. But of gas from Wigan cannel, when the whole product is mingled together, 100 measures do not saturate more than 155 of oxygen, and give 88 measures of carbonic acid. Oil gas, therefore, from this comparison, may be inferred to contain, in a given volume, twice the quantity of combustible matter that is present in the average of gas from cannel coal, owing most probably to a larger proportion of some of the heavier gases enumerated in the table, p. 360. Of the fourth species the whole that is present in oil gas may be separated from it, as Mr. Faraday found, either by oil or by sulphuric acid over mercury. In this way, good oil gas lost 22 or 23 per cent. of its volume; and the olefiant gas was not diminished, except by contact during some hours. He does not apprehend that gas contains any more volatile ingredient than No. 4 of the table.

The experiments of Mr. Brande led him to conclude, that to produce the light of ten wax candles for one hour, there were required

2600	cubical inches of	olefiant gas.
4875		oil gas.
13120		coal gas.

But it seems probable that the coal gas, employed in his experiments, was below the general standard, and that it is a fair average to consider 1 volume of oil gas as equivalent in illuminating power to 2 or at most 2¼ volumes of gas from coal. This estimate agrees with the experience of the late Mr. Creighton, of Glasgow, author of the excellent article "Gas lights," in the Supplement to the Encyclop. Britan. Oil gas he considers as superior, in an equal volume, to good average coal gas, in the proportion of only 2 to 1; and he has given the following Table of the comparative expense of lighting with these two gases, and with oil and tallow.

	s.	*d.*
Valuing the quantity of light given by 1 lb. of tallow in candles at - - - - - - - - - - - - - - - -	1	0
An equal quantity of light from sperm. oil consumed in an Argand's lamp, will cost - - - - - - - -	0	6½
Do. from whale oil gas - - - - - - - - - - - -	0	4½
Do. from coal gas - - - - - - - - - - - - - -	0	2¾

Twenty cubic feet of coal gas, or ten of oil gas, he considers as equivalent to a pound of tallow; and 5000 grains of good sperm. oil to 7000 of tallow, or 1lb. avoirdupois.

Drs. Turner and Christison of Edinburgh have, more recently, endeavoured to reconcile the contradictory statements respecting oil and coal gas, in a memoir full of excellent practical information, which they published in Dr. Brewster's Edinburgh Journal for July 1825. With a complete knowledge of all the circumstances essential to a fair comparison, they carefully tried the illuminating powers of oil gas sp. gr. .910, and coal gas sp. gr. .578, both with common and with Argand's burners; and the average result of their various trials was that the illuminating power of the oil gas employed was to that of the coal gas, under equal volumes, as 2.25 to 1. The gas from common resin, for which a patent has been taken out by Mr. Daniel (Quart. Journ. N. S. i. 217) has not, so far as I am aware, been accurately analyzed.

The advantages of oil gas over gas from coal are, that smaller distilling vessels are required; that gazometers and conduit pipes of half the capacity are sufficient; that no washing apparatus is necessary; that the trouble and expense of removing waste materials are avoided; and that the gas affords a much brighter light, with a smaller production of heat, and also of water. When only a moderate quantity of light is required; when it is an object to save room or labour; and in countries where coal is dear, oil gas is entitled to a decided preference; but it cannot be brought into competition with coal gas, where coal is cheap, or where the establishments to be lighted are of very considerable magnitude, and of such a nature as to allow of their being freely ventilated.

Of the comparative value of different compounds of hydrogen and charcoal for the purpose of illumination, it still appears to me that the only accurate test is the one which I proposed in Nicholson's Journal for 1805, *viz.* the quantities of oxygen gas required for the combustion of equal volumes. In other words, the illuminating powers of the different gases will be proportional to the number of volumes of gaseous carbon condensed into one vol. of inflammable gas; and of these the oxygen consumed, and carbonic acid produced, afford an accurate measure. If 100 vols., for instance, of one gas require for perfect combustion 100 vols. of oxygen, and 100 vols. of another gas take 200 of oxygen, the value of the second will be double that of the first. Specific gravity, though a guide to a certain extent, is not a sufficient one; for the weight of a gas may be owing to a large proportion of carbonic oxide, which is capable of giving out only a very small quantity of light. Photometrical experiments, also, appear to me to require greater perfection in the instruments that have been invented for that purpose, before we can implicitly trust to results obtained by their means; but there can be no fallacy in the combustion of these gases by oxygen, if conducted with ordinary care, and especially if, in each instance, an average be taken of two or three trials, which need not occupy more than a few minutes. Nor can it admit of a doubt that, other circumstances being equal, the brilliancy of light, evolved by the combustion of gases which are constituted of purely inflammable matter, will bear a proportion to their densities, perhaps even a greater proportion than one strictly arithmetical; because, while by the combustion of denser gases a higher temperature is produced, the cooling agencies remain the same. It is probable, therefore, that of two gases, composed of the same ingredients, that which has a double density will afford somewhat more than a double quantity of light.

ART. 6.—*On the Fire-Damp of Coal Mines, and the Construction and Principle of the Safety-Lamp of Sir H. Davy.*

The fire-damp of coal mines was proved, by an analysis of it which I published in Nicholson's Journal for 1806 (xix. 149), to be identical in composition with light carbureted hydrogen. This conclusion coincides with the subsequent results of Sir H. Davy, (Phil. Trans. 1816) who has enlarged our knowledge of the chemical history of the fire-damp by several important facts, and has been led, by an ingenious and happy chain of reasoning, to a discovery most important to the interests of humanity. The most readily explosive mixture of fire-damp with common air he found to be one measure of the inflammable gas to seven or eight of air. The mixture was not capable of being set on fire by charcoal in a state of active combustion, nor by iron ignited to a red or even to a white heat, except when in a state of brilliant combustion; in which respects, the fire-damp differs from other combustible gases.

It was in attempting to measure the expansion, occasioned by the combustion of a mixture of fire-damp and air, that Sir H. Davy discovered a fact, which afterwards led him to the most novel and important results. An explosive mixture could not, he ascertained, be kindled in a glass tube so narrow as $\frac{1}{7}$ of an inch diameter; and when two separate reservoirs of an explosive mixture were connected by a metallic tube, $\frac{1}{5}$ of an inch diameter and $1\frac{1}{2}$ inch in length, and one of the portions of gas was set on fire, the explosion did not extend to the other. Fine wire sieves or wire gauze, interposed between two separate quantities of an explosive mixture, were also found to prevent the combustion of one portion from spreading to the other. A mixture of fire-damp and air, in explosive proportions, was deprived of its power of exploding, by the addition of about $\frac{1}{7}$ its bulk of carbonic acid or nitrogen gas.

Reflection on these facts suggested to Sir H. Davy the possibility of constructing a lamp,* in which the flame, by being supplied with only a limited quantity of air, might produce carbonic acid and nitrogen, in such proportion as to destroy the combustibility of explosive mixtures; and which might, also, by the nature of its apertures for giving admittance and exit to the air, be rendered incapable of spreading combustion to the surrounding atmosphere, supposing this to be an inflammable one.

This most desirable object was accomplished by the use of air-tight lanterns, supplied with air through tubes or canals of small diameter, or through apertures covered with wire gauze below the flame, and having a chimney at the upper part on a similar system for carrying off the foul air. The apparatus was afterwards simplified by covering or surrounding the flame of a lamp or candle with a cylindrical wire sieve, having at least 625 apertures in a

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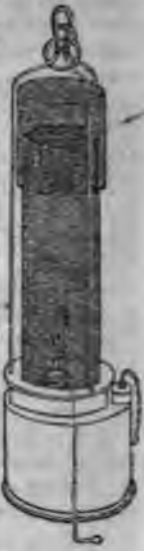
* A full history of the Safety Lamp, and of the chemical researches connected with it, has been published by Sir H. Davy, 8vo. printed for R. Hunter, 1818. In the Phil. Mag. l. 387, a document, also, may be found, which fully establishes his claim to the priority of the invention.



square inch. (See the sketch.) Within this cylinder, when the fire-damp encompassing it is to the air as 1 to 12, the flame of the wick is seen surrounded by the feeble blue flame of the gas. When the proportion is as 1 to 5, 6, or 7, the cylinder is filled with the flame of the fire-damp; but though the wire gauze becomes red-hot, the exterior air, even when explosive, is not kindled. The lamp is therefore *safe* in the most dangerous atmospheres, and has been used most extensively in the mines of Whitehaven, Newcastle, and other places, without the occurrence, so far as I know, of a single failure or accident.

The effect of the safety-lamp depends on the cooling agency of the wire gauze, exerted on the portion of gas burning within the cylinder. Hence a lamp may be secure, where there is no current of an explosive mixture to occasion its being strongly heated; and yet not safe, when the current passes through it with great rapidity. But any atmosphere, however explosive, may be rendered harmless, by increasing the cooling surface; which may be done, either by diminishing the size of the apertures, or by increasing their depth, both of which are perfectly within the power of the manufacturer of the wire gauze.

When a small coil of platinum wire is hung above the wick of the lamp within the wire gauze cylinder, the metal continues to glow, long after the lamp is extinguished, and affords light enough to guide the miner in what would otherwise be impenetrable darkness. In this case, the combustion of the fire-damp is continued so slowly, and at so low a temperature, as not to be adequate to that ignition of gaseous matter which constitutes flame, though it excites a temperature sufficient to render platinum wire luminous. A similar ignition of platinum wire, it has been found, may be supported for many hours, by surrounding the flame of a spirit lamp with small coils of that metal not exceeding $\frac{1}{100}$ of an inch in diameter. Twelve coils of this wire, twisted spirally round the tube of a tobacco-pipe, or round any thing that will render the coils about $\frac{3}{10}$ of an inch in diameter, are to surround, six the wick of the lamp, and six to remain elevated above the wick. The wick should be small, and quite loose in the burner of the lamp; and the fibres of the cotton, surrounded by the coil, should be laid as straight as possible. When the lamp, after being lighted for a few moments, is blown out, the platinum wire continues to glow for several hours, as long as there is a supply of spirit of wine, and to give light enough to read by; and sometimes the heat produced is sufficient to rekindle the lamp spontaneously. (Thomson's Annals, vol. xi.)

ART. 7.—*Of the Combination of Chlorine with Carbo-hydrogen.*

This gas was first obtained by Dr. Thomson, by heating [illegible] *regia* with *pyroxylic spirit;* and has hitherto been examined by him only. The method of obtaining it, free from other gases, involves longer details than I deem it advisable to enter upon, and I refer therefore to his paper in the Transactions of the Royal Society of Edinburgh, for 1827. The new gas is chiefly interesting, as, if the analysis of it be correct, it exhibits the first distinct example of the actual existence of that compound of an atom of carbon with an atom of hydrogen which I have stated hypothetically at page 360; still, however, not in an insulated state, but in union with an atom and a half (so to speak) of chlorine. Its specific gravity by experiment is 4.1757, and this is not very remote from the theoretical view, that each volume is constituted of

1 volume carbon vapour	0.4166
1 volume hydrogen gas	0.0694
1½ volume chlorine	54.0000
Density by calculation	54.4860

Each volume consumes 2 vols. of oxygen gas, and gives 1⅓ vol. carbonic acid, the remaining ⅔ds. of oxygen having formed water. Dr. Thomson has proposed the name of *sesqui-chloride of carbo-hydrogen*, as conveying a just notion of its composition.

SECTION III.

Compounds of Hydrogen with Phosphorus.

In the chapter on Phosphorus, it has been shown that great uncertainty still prevails, respecting the proportions in which that body unites with oxygen. Its compounds with hydrogen are not less imperfectly understood, and even their number is still undetermined. All writers on the subject, with the exception of Mr. Dalton, who contends that there is only one species of phosphureted hydrogen, admit the existence of two at least. To these, Dr. Thomson has added a third, which has not, I believe, been as yet examined by other chemists. On this obscure topic I shall give an abstract of the best evidence that can be obtained, leaving the reader to form his own opinion, and only premising, that without more facts, it is impossible to arrive at any certainty, as to the constitution of these compounds.

ART. 1.—*Bi-hydroguret of Phosphorus.*

The name which I have adopted for this gas, was first applied to it by Dr. Thomson; and it has been abbreviated by others into *bi-hydruret*. Dumas has proposed to call it *proto-phosphureted hydrogen*. But, till its composition is clearly ascertained, it would have been better not to have changed the name assigned by its original discoverer, Sir H. Davy, who termed it *hydro-phosphoric* *gas*, for any other name, depending upon theoretical views of its constitution.

Davy first obtained this gas by heating solid hydrate of phosphorous acid (page 325) in a small glass retort, and receiving the gas over mercury, allowing enough to escape to displace the air of the retort. The gas that next comes over, while the heat is moderate, is most pure; for, towards the close of the process, it becomes contaminated with about one-fourth its volume of hydrogen. Heat liberates it also from hypo-phosphorous acid. Dumas obtained it of such purity as to be mixed with not more than from 1 to 5 per cent. of hydrogen gas, by acting on phosphuret of calcium with concentrated muriatic acid. (Ann. de Ch. et de Ph. xxxi. 112. On its preparation, see also Rose, same work, xxxiv. 177.)

This gas has an unpleasant odour, less so, however, than that of per-phosphureted hydrogen. Water absorbs about an eighth of its volume. Its specific gravity was found by Davy to be twelve times that of hydrogen, or 0.87, air being unity; but the gas which he employed was evidently mixed with hydrogen. Dumas availed himself of a property, not known by Davy, to determine the exact purity of the gas which he weighed. It consists in exposing a known volume to a solution of sulphate of copper, which absorbs the pure portion only of the gas, leaving the hydrogen untouched. Making due correction for the latter gas, he found the sp. grav. of pure proto-phosphureted hydrogen to be 1.214, air being 1.

This gas does not burn spontaneously when suffered to escape into the air, but detonates violently when mixed with oxygen, and heated to about 300° Fahr.; or when the mixture is rarefied, by simply raising the level of the mercurial surface within the tube, sufficiently above the surface of the mercury in the trough. Dr. Thomson, with whom Dumas agrees in this instance, states that 1 vol. requires for complete combustion 2 vols. of oxygen, forming then *phosphoric* acid. If 1.5 vol. only of oxygen be used, the product is *phosphorous* acid. The manipulations necessary to cause oxygen to unite in these proportions will be found in Dumas's Essay, p. 119.

Sulphur, heated in this gas, converts it into sulphureted hydrogen, 4 vols. of the latter resulting from 3 of the former. But as sulphureted hydrogen itself has its bulk contracted $\frac{1}{9}$ by fused sulphur, $135 + \frac{135}{9} = 150$ is the true product of sulphureted hydrogen from 100 vols. of the proto-phosphureted gas. (Dumas.) By acting on 1 vol. of the gas with potassium, Davy obtained 2 vols., Gay Lussac and Thenard only 1.5 vol. of hydrogen gas. Dumas also, by passing 1 vol. of the gas over heated bi-chloride of mercury, obtained 3 vols. of muriatic acid gas, equivalent to 1.5 of hydrogen. The proportion then of 1.5 vol. of hydrogen, in 1 vol. of proto-phosphureted hydrogen, seems sufficiently established. Now 1.5 hydrogen saturate 0.75 oxygen; and, subtracting the latter number from the whole oxygen spent when phosphoric acid is formed ($2 - 0.75 = 1.25$), we have $\frac{5}{4}$ of a vol. of oxygen consumed by the phosphorus. Also by deducting 0.75 from 1.5 vol. of oxygen, spent when phosphorus acid is formed, we have ($1.50 - 0.75 =$) 0.75, or ¾ vol., for the oxygen of phosphorous acid. The oxygen then of the phosphoric and phosphorous acid is as the numerations of those fractions, *viz.* as 5 to 3.

Reasoning on these experimental data, Dumas conceives that in every 2 vols. of proto-phosphureted hydrogen gas we have

1 vol. vapour of phosphorus - - - -	2.2052
3 vols. hydrogen (.694 × 3) - - - -	0.2082
	2) 2.4134
Sp. gr. of the gas - - - -	1.2067

The specific gravity deduced by calculation agrees then very nearly with the experimental result already stated, *viz.* 1.214. The proportions by weight of hydrogen to phosphorus is 0.2082 : 2.2052, which is the same as 1 : 10.61. The gas cannot be considered as a binary compound, for the last mentioned number falls short of that derived in a former chapter as the most probable equivalent of phosphorus, *viz.* 12. (See page 327.)

2. *Perphosphureted Hydrogen Gas, Hydroguret, or Hydruret, of Phosphorus.*

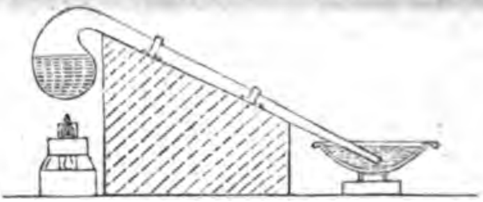
This gas was discovered by Gengembre in 1783. It is easily procured by heating a little phosphorus in a retort over a lamp, with solution of pure potassa, or with a mixture of lime and water of the consistence of cream; but when thus formed, only 37 or 38 parts out of 100 are the gas in question, 62 or 63 being hydrogen. It is also disengaged by heating fragments of phosphorus with powdered hydrate of lime, or by adding small lumps of phosphuret of calcium to very dilute muriatic acid. The gas got by acting on zinc and phosphorus with dilute sulphuric acid is mostly hydrogen. The purest specimen of this gas, ever obtained by Dumas, was formed by bringing phosphuret of calcium into contact with water. It contained, in 100 vols., only 12 or 13 vols. of hydrogen gas. From whatever source obtained, the less the heat beyond what is absolutely required to liberate it, the more free is the product from common hydrogen gas. Its most remarkable property is that, when mixed with atmospheric air or with oxygen gas, at ordinary temperatures, it is spontaneously combustible, even when obtained by methods that yield at the same time much hydrogen. Its specific gravity varies with the proportion of hydrogen gas with which it is contaminated. Sir H. Davy found the limits to extend from .400 to .700; Dr. Thomson fixed it at .9027; Mr. Dalton recently at 1.100 (New System, ii. 170). Dumas, making due correction for the hydrogen gas mingled with it, makes its true sp. gr. 1.761.

By standing about a month in a receiver over mercury, it deposits a third of its phosphorus, loses its property of spontaneous accension, and is converted, without change of volume, into bi-hydruret of phosphorus. (Dumas.) Electric explosions decompose it, without expanding it, according to Thomson; but Mr. Dalton finds that 1 vol. becomes $1\frac{1}{4}$ very nearly. Gay Lussac and Rose agree that it is decomposed by a heat below ignition.

The quantity absorbed by water is stated by Davy at $\frac{1}{26}$ the vol. of the water; by Dalton at $\frac{1}{27}$; and by Dr. Thomson at $\frac{1}{50}$. These differences depend, doubtless, on the variable purity of the gas, and the quantity and quality of the air remaining even in boiled water. The gas is absorbed also by liquid sulphate of copper and chloride of lime. (Dalton and Rose.) The latter agent converts the phosphorus into phosphoric acid.

When allowed to escape into the atmosphere, it inflames spontaneously, and a beautiful zone of white vapour is produced, which enlarges as it ascends. This takes place, even at the temperature of freezing mercury, as Rose observed. (Ann. de Chim. et de Ph. Feb. and Aug. 1827.)

In preparing this gas from phosphorus and solution of potassa, for the striking experiment of its spontaneous accension, both the body and neck of the retort should be entirely filled with the solution, which Dr. Coxe, of Philadelphia, recommends to be almost boiling hot. He employs a retort holding from half a pint to a pint; and after introducing both the phosphorus and the solution, fixes its neck on an inclined plane formed of a block of wood, the upper extremity of which is overhung by the body of the retort, while its mouth projects over the lower end, and is dipped into a small bowl filled with a hot solution of potassa, as represented in the figure.



The gas extricated by the flame of a lamp, accumulates; and, forcing the alkaline solution down the neck, at length escapes, through the hot solution in the bowl, into the air, where it inflames. Should the heat slacken, and an absorption ensue, nothing passes into the retort but the hot solution of alkali from the bowl; and this, as the retort is secured from being displaced, does no harm. In this way a torrent of gas may be kept up, as long as there remains sufficient materials in the retort; and all danger of breaking the retort is avoided.

When fine iron or copper wire is heated in 100 of the gas (reckoned pure), dried by blotting paper, 150 volumes of hydrogen gas were obtained on the average of several experiments. (Dumas.) Deuto-chlorides decompose it without evolving hydrogen; and sulphurets yield sulphureted hydrogen and phosphurets of the respective metals.

When admitted by bubbles into pure oxygen gas, each bubble detonates vehemently, and some phosphorus is precipitated. But by diluting the oxygen with carbonic acid, and warming the jar to

212° Fahr., the combustion is complete. In this case, phosphorous acid only is produced, and 8 volumes of the hydruret consume 15 of oxygen. (Dumas.) The maximum quantity of oxygen absorbed by 8 volumes, on the same authority, is 21 volumes. But as each volume of the inflammable gas contains 1.5 volumes of hydrogen, 8 volumes must be equivalent to 12 of hydrogen, requiring 6 volumes of oxygen. Subtracting 6 from 15, we have 9 for the oxygen in phosphorous acid; and, taking 6 from 21, we have 15 for the oxygen in phosphoric acid; and 9 : 15 : : 3 : 5, numbers denoting the proportion of oxygen, which, it would appear, exists in those two acids.

The theoretical constitution of this gas, according to Dumas, is

1.5 volume of phosphorous vapour - - - -	3.3078
3 volumes of hydrogen gas - - - - - - -	0.2082
	3.5160

Condensed into 2 volumes. Dividing therefore 3.5160 by 2, we have 1.7580 for the sp. gr. of the gas; and the proportion by weight of the hydrogen to the phosphorus is as 1 to 11.08. Supposing it to be a compound of an atom of each element, the equivalent of phosphorus, thus deduced, would be represented by a number not very remote from 12. It may be proper to add, that Rose's analysis of this gas gives a less proportion of phosphorus, *viz.*

Hydrogen - - - - -	8.68 - - - - - -	1.
Phosphorus - - - -	91.32 - - - - - -	10.52
	100.	

3. *Subphosphureted Hydrogen Gas.*

Phosphureted hydrogen, by standing some time, deposits, according to Dr. Thomson, one-fourth of its phosphorus, and loses its property of spontaneous inflammability. In this state, sulphur may be sublimed in it without altering its volume. For perfect combustion, 1 volume requires 1.25 volume of oxygen gas, of which 0.75 goes to the phosphorus and 0.50 to the hydrogen; or, if fired with barely oxygen enough to saturate the phosphorus, about 1 volume of hydrogen remains.

I am not aware, however, that a gas, thus characterized, has been recognised by any other chemist; and it has already been stated, that the effect of standing undisturbed was found by Dumas to be the conversion of the perphosphureted into the protophosphureted species.

No one can have attentively read the account, which I have given, of the compounds of phosphorus and hydrogen, without being aware that much yet remains to be done before we can, with any confidence, assign their constitution. The imperfect state of our knowledge on this subject will be still more apparent to those who consult the original memoirs. In these, discrepancies are to be found, as to the results of experiments, that can only be explained by supposing that chemists, of so much skill and accuracy, must have operated on gases nominally the same, but actually varied as to their composition, by the temperature and other circumstances under which they have been produced.

SECTION IV.

Hydrogen with Sulphur.

Sulphureted Hydrogen Gas.

Sulphureted hydrogen gas, though known to Rouelle, was first investigated by Scheele in 1777; and afterwards by Bergman, Kirwan, Berthollet, Chaussier, Davy, Gay Lussac, Thenard, Dalton, Berzelius, and other chemical philosophers. It may be formed by repeatedly subliming sulphur in hydrogen gas; but this process is of little use, except to prove its nature by direct synthesis; for it is impossible thus to convert nearly the whole of any given quantity of hydrogen into the compound gas. For the purposes of experiment, it may be procured by any one of the following methods; but the fourth is, on the whole, the best.

1. By the action of diluted sulphuric acid on sulphuret of iron, prepared in the following manner. A bar of iron is to be heated to a white or welding heat in a smith's forge, and, in this state, is to be rubbed with a roll of sulphur. The metal and sulphur unite, and form a liquid compound, which falls down in drops. These soon congeal, and the compound must be preserved in a well-closed phial. The sulphuret, prepared by melting iron filings with sulphur in a crucible, does not answer the purpose equally well, because the gas which it affords is mixed with a good deal of hydrogen gas, evolved by the iron which is always in excess.

2. Gay Lussac prepares sulphuret of iron, by introducing into a matrass two parts by weight of fine iron filings and one of flowers of sulphur. To these water is added in sufficient quantity to give a thickish consistence; and the matrass is heated a little, to favour the combination, which is indicated by a copious disengagement of heat, and by the whole mass assuming a black colour. From this compound, sulphuric acid, diluted with four times its volume of water, separates sulphureted hydrogen in great abundance. It is better to prepare the compound when wanted, than to keep it ready made; because, unless very carefully preserved from contact with the air, it becomes less fit for the purpose of affording gas. (Ann. de Chim. et Phys. vii. 314.)

3. The sulphuret of potassa (or compound so called), prepared by boiling flowers of sulphur with liquid potassa quite free from carbonic acid, gives sulphureted hydrogen, when acted upon by diluted sulphuric or muriatic acid.

4. On powdered sulphuret of antimony (crude antimony of the shops) pour five or six times its weight of muriatic acid (sp. gr.

1.160, or thereabouts), in a retort or gas bottle, and apply the heat of a lamp. Sulphureted hydrogen will be disengaged in abundance, and of great purity.

Whichsoever of these processes be followed, it is advisable, as the gas is absorbed quickly by standing over water, to receive it into bottles provided with glass stoppers, and, after filling them entirely with the gas, to introduce the stopper.

Liquid Sulphureted Hydrogen.

Mr. Faraday obtained sulphureted hydrogen *in a liquid form* by producing it under pressure, with the apparatus described in the section on carbonic acid, from sulphuret of iron and muriatic acid. It was then colourless, limpid, and excessively fluid. Ether, when compared with it in similar tubes, appeared tenacious and oily. It did not seem more consistent at 0° than at 45° Fahr., and, when raised from the former to the latter temperature, the only effect was that part of the liquid rose in vapour, and its quantity diminished. When a tube containing it was opened under water, the liquid rushed immediately into gas, which, when collected, had all the properties of sulphureted hydrogen. The refractive power of the liquid appeared rather greater than that of water; it decidedly surpassed that of sulphurous acid. By a small gauge, introduced into the tube in which it was produced, the pressure of its vapour was nearly equal to 17 atmospheres at 50° Fahr. (Phil. Trans. 1823, p. 192.)

II. When in the *form of gas*, sulphureted hydrogen has the following properties:

Its smell is exceedingly offensive, resembling that of putrefying eggs, or of the washings of a gun-barrel, to both which, indeed, it imparts their offensive odour.

It appears to be one of the most unrespirable of all the gases, for a small bird died immediately in air containing only $\frac{1}{1500}$ of its volume of sulphureted hydrogen; a dog perished in air mingled with $\frac{1}{800}$; and a horse in air containing $\frac{1}{250}$. (Thenard, i. 723.)

It is inflammable, and burns either silently or with an explosion, according as it is previously mixed, or not, with oxygen gas or atmospheric air. During this combustion, water results from the union of the hydrogen with the oxygen, and sulphurous acid, with a little sulphuric acid, from that of the oxygen and sulphur. Two volumes require 3 of oxygen gas, 1 volume of which saturates the hydrogen, and 2 volumes the sulphur.

It tarnishes silver, mercury, and other polished metals; and instantly blackens white paint and solution of acetate of lead. By direct experiments, I have found that 1 volume of this gas, mixed with 20,000 volumes of hydrogen, of carbureted hydrogen, or of common air, produces a sensible discoloration of white lead, or of oxide of bismuth, mixed with water, and spread upon a piece of card. In this way we may ascertain the presence in coal gas of extremely small quantities of sulphureted hydrogen. We may even form a tolerable estimate of its proportion, when too minute to be otherwise measured, by comparing the shade of colour, with a series that has been prepared for the purpose, by exposing slips of card, covered with white lead and water, to mixtures of sulphureted hydrogen and common air in known proportions.

Sulphureted hydrogen is absorbed by water, which takes up its own bulk, or, according to Saussure, twice and a half, or to Gay Lussac, three times, its bulk of the gas; but, in order to obtain so considerable an absorption, the gas submitted to experiment should be perfectly free from common hydrogen. Water thus saturated acquires the peculiar smell of the gas. It is this gas which gives to the Harrogate, and some other natural waters, their disagreeable odour. Liquid muriatic acid absorbs at least three times its volume of the gas; and sulphuric acid, diluted with an equal weight of water, once and a half its volume.

Water, saturated with this gas, reddens the infusion of violets, in this respect producing the effect of an acid. From this and other properties, some of the German chemists have proposed for it the name of *hydrothionic acid;* and Gay Lussac has given it the objectionable name of *hydro-sulphuric acid*, a term which would be much more properly applied to liquid sulphuric acid. Berzelius, to suit his theoretical views, has proposed the name of *sulfide hydrique*, and for the compounds, which it forms with bases, that of *sulpho-hydrates* or *sulphydrates*. (Ann. de Ch. et de Ph. xxxii.) There can, indeed, be no doubt that sulphureted hydrogen performs the most important functions of an acid; and any name that will distinctly describe it, without leading to its being confounded with any of the compounds of sulphur and oxygen, will be entitled to adoption.

Water impregnated with sulphureted hydrogen, when exposed to the atmosphere, becomes covered with a pellicle of sulphur. Sulphur is even deposited when the water is kept in well-closed bottles.

On the addition of a few drops of nitric or nitrous acid to the watery solution, sulphur is instantly precipitated. In this case the oxygen of the acid combines with the hydrogen of the gas, and the sulphur is separated. When a small quantity of strong fuming nitrous acid is poured into a wide-mouthed receiver containing sulphureted hydrogen gas, decomposition takes place, and a beautiful flame spreads through the interior of the vessel. (Ann. of Phil. viii. 226.) The gas is decomposed, also, when transmitted through sulphuric, nitric, or arsenic acids. (Quart. Journ. of Science, &c. ii. 152.)

Sulphureted hydrogen is decomposed by mixture with chlorine, which seizes the hydrogen, and sulphur is precipitated. Vogel obtained, in this way, a liquid analogous to the chloride of sulphur of Dr. Thomson. Iodine decomposes sulphureted hydrogen, and hydriodic acid is formed.

It is decomposed, also, when long kept in a state of mixture with atmospheric air, the oxygen of which combines with the hydrogen, and forms water, while the sulphur is precipitated.

A succession of electric explosions throws down sulphur from it, and the volume of the gas remains unaltered. A similar effect is produced by passing it through an ignited porcelain tube, but it cannot in this way be entirely decomposed. Its elements are also disunited by exciting vivid ignition, by Voltaic electricity, in platinum wires surrounded by it; sulphur is deposited, and an equal volume of hydrogen remains.

It is decomposed when passed over ignited charcoal, and is converted into carbureted hydrogen gas. Dumas has observed, that when sulphur is heated in contact with sulphureted hydrogen, the latter undergoes some change, the nature of which he has not explained, but which is indicated by a contraction of one-tenth of its volume. (Ann. de Ch. et de Ph. xxxi. 117.)

Sulphureted hydrogen, both in the state of a gas and of watery impregnation, precipitates all metallic solutions, excepting those of iron, nickel, cobalt, manganese, titanium, and molybdenum.

It is abundantly absorbed by alkalies, and by all the earths, excepting alumina and zirconia. This property affords a ready method of ascertaining its purity; for, if it be agitated with a solution of potassa by means of the apparatus represented fig. 20 or 21, the unabsorbed residue will show the amount of the impurity, which is commonly hydrogen gas. Its alkaline and earthy combinations are termed *hydro-sulphurets*, or by Berzelius, as already mentioned, *sulpho-hydrates*. According to that philosopher, they are few in number, not exceeding eight. They precipitate the salts of manganese, zinc, cerium, iron, glucina, and yttria, with a disengagement of sulphureted hydrogen. They are decomposed partially by carbonic acid; and, reciprocally, the alkaline carbonates have a portion of their acid displaced by sulphureted hydrogen, an apparent anomaly, which is explained by Gay Lussac. (Ann. of Phil. April, 1826, p. 279.) The individual compounds of sulphureted hydrogen will be described with their respective bases.

Sulphureted hydrogen unites with an equal volume of ammoniacal gas, or, if transmitted through the watery solution of that gas, it is rapidly absorbed, and the liquid, which has a yellow colour, and a strong smell of sulphureted hydrogen, is very useful as a test of certain metals.

When 3 volumes of sulphureted hydrogen gas, and 2 volumes of sulphurous acid gas, both dry, are mixed together over mercury, they are entirely condensed into a solid body, which adheres firmly to the inside of the vessel. This substance is of an orange yellow colour. Its taste is acid and hot, and it leaves a permanent impression on the mouth. When perfectly dry, it does not change litmus paper; but reddens it immediately when moistened. Water, alcohol, nitric acid, and sulphuric acid, decompose it, and disengage sulphur. It does not precipitate the watery solution of baryta. It is decomposed at a moderate heat, and pure sulphur remains. Dr. Thomson, who discovered this compound, considers it as an acid, and terms it *hydro-sulphurous acid*. He states it to be constituted of 5 atoms of sulphur + 4 atoms of oxygen + 5 atoms of hydrogen. (Ann. of Phil. xii. 441.)

When potassium or sodium is made to act on sulphureted hydrogen gas, a brilliant combustion takes place; a quantity of hydrogen gas is evolved, precisely equivalent to that which the same weight of metal would have separated from water; the metal loses its lustre, and becomes greyish, or amber coloured, or reddish; and, by the action of diluted muriatic acid, the whole of the sulphureted hydrogen is recovered. This experiment proves, that sulphureted hydrogen, and consequently sulphur, contain no oxygen; for then the potassium, having had its affinity for oxygen partly satisfied, would not, after being acted on by the gas, evolve the original quantity of sulphureted hydrogen from water. In this case Gay Lussac conceives that an atom of potassium decomposes an atom of sulphureted hydrogen, the sulphur of which it seizes, and that this sulphuret combines with another atom of sulphureted hydrogen. During solution the atom of metal probably decomposes an atom of water, and an additional atom of sulphureted hydrogen is re-produced, which, with the atom of potassa, form a bi-hydro-sulphuret. (30 Ann. Ch. et Ph. p. 26.)

The specific gravity of sulphureted hydrogen gas has been variously represented. Sir H. Davy states the weight of 100 cubic inches at 36.5 grains, and its specific gravity, therefore, at 1.196. Gay Lussac and Thenard determined its specific gravity to be 1.1912 by experiment, or 1.1768 by calculation; hence 100 cubic inches, if the first of those two numbers be adopted, should weigh 36.33 grains. (81 Ann. de Chim. 26.)

The latest attempt to ascertain its specific gravity is that of Dr. Thomson, the experimental result of which was 1.1788, and, after the necessary corrections, 1.1805. Hence, 100 cubic inches (bar. 30, therm. 60°) weigh 35.89 grains. To determine its composition, we have only to subtract the specific gravity of hydrogen from that of the compound gas, and the remainder will show the weight of the sulphur. Thus,

Sp. grav. of sulphureted hydrogen gas - -	1.180
———— of hydrogen gas - - - - - - -	0.069
Sp. grav. of vapour of sulphur	1.111

One volume of sulphureted hydrogen is constituted, therefore, of 1 volume of the vapour of sulphur = 1 atom (1.111) + 1 vol. of hydrogen gas = 1 atom (0.069). But the numbers 0.069 and 1.111 are in the proportion very nearly of 1 to 16, which gives exactly the same relative weight for the ultimate particle of sulphur, as that deduced from the composition of sulphuric acid.

Bi-sulphureted Hydrogen.

This compound was discovered by Scheele, and afterwards examined by Berthollet. (Ann. de Chim. tom. xxv.) It is obtained when the liquid, forming by boiling flowers of sulphur with solution of potassa, is poured, by little and little, into muriatic acid.

A very small portion only of gas escapes; and, while the greater part of the sulphur separates, one portion of it combines with the sulphureted hydrogen; assumes the appearance of an oil; and is deposited at the bottom of the vessel. Or we may dissolve sulphur in a boiling solution of pure potassa; and into a phial, containing about one-third its capacity of muriatic acid, of the specific gravity 1.07, pour about an equal bulk of the liquid compound. Cork the phial, and shake it; the bi-sulphureted hydrogen gradually settles to the bottom in the form of a brown, viscid, semifluid mass. Its properties are the following:

1. Its taste and smell resemble those of putrid eggs, but are less offensive. Its precise specific gravity is unknown, but it is heavier than water, and descends through it. It is inflammable, and burns in the air with a smell of sulphurous acid.

2. If gently heated, sulphureted hydrogen gas exhales from it; the bi-sulphuret loses its fluidity; and a residue is left, consisting merely of sulphur.

3. It is constituted, according to Mr. Dalton, of 2 atoms of sulphur = 32, with 1 atom of hydrogen, and is represented by the number 33.

4. It combines with alkalies and earths; and forms with them a class of substances called *hydrogureted sulphurets*.

The hydrogureted sulphurets are also formed by boiling, along with a sufficient quantity of water, the alkaline, or earthy base, with flowers of sulphur. Thus a solution of pure potassa, pure soda, or of baryta or strontia, may be changed into an hydrogureted sulphuret. As an illustration of what may be supposed to take place, let us imagine 3 atoms of sulphur to act simultaneously on 1 atom of water (= 1 atom of hydrogen + 1 atom of oxygen); 2 atoms of sulphur with the atom of hydrogen will compose an atom of bi-sulphureted hydrogen, which, with an atom of potassa, will form 1 atom of hydrogureted sulphuret of potassa. The third atom of sulphur will unite with the free atom of oxygen, and form hypo-sulphurous acid.

To prepare the compound with base of lime, the powdered earth, mixed with sulphur, may be boiled with a proper quantity of water, and the solution filtered, or cleared by subsidence. One hundred grains of lime, or 134 of hydrate, dissolve about 215 of sulphur, and afford a liquid of 1.146 specific gravity.

Another method of forming, by a very simple process, the hydrogureted sulphurets, consists in digesting, in a gentle heat, a hydro-sulphuret with powdered sulphur, an additional atom of which is thus dissolved, while part of the sulphureted hydrogen escapes. (Thenard, 83 Ann. Ch. p. 132.)

Hydrogureted sulphurets have the following properties:

1. They have a deep greenish yellow colour; an acrid and intensely bitter taste; and an excessively offensive smell.

2. They deposit sulphur when kept in close vessels; become much more transparent and lighter coloured; and less offensive to the smell.

3. They rapidly absorb oxygen from the atmosphere, and from

oxygen gas. Hence their employment in eudiometry. (See chap. vii. sect. 2.)

4. On the addition of dilute sulphuric, or muriatic, or of certain other acids, they are decomposed. Sulphureted hydrogen gas is evolved, and sulphur is precipitated.

5. When boiled in contact with filings of silver or of copper, and of those metals only, Vauquelin found that they lose their excess of sulphur, and become simple hydro-sulphurets.

Recapitulation.

There are, therefore, three distinct combinations of sulphur and its compounds, with metals, and with alkalies and earths. The first consist simply of sulphur, united with a metallic base, and these alone are properly called *sulphurets.* The second are composed of sulphureted hydrogen, united with an oxidized base, and are called *hydro-sulphurets.* The third contain bi-sulphureted hydrogen, attached to an oxidized base, and constitute *hydrogureted sulphurets.*

The sulphurets with metallic bases can exist, as such, only in a dry state; for the moment they begin to dissolve in water, a decomposition of that fluid commences; sulphureted hydrogen is formed; and of this a part is disengaged, while another part, uniting with an additional proportion of sulphur, composes bi-sulphureted hydrogen, and this last, uniting with the base, forms an hydrogureted sulphuret. At the same time, Berthollet, (Ann. de Ch. xxv. 239, 269,) supposed that sulphuric acid is generated by the action of the sulphur on the oxygen of the water. This, however, Gay Lussac has proved takes place only when the sulphuret has been formed at an unnecessary degree of heat, and that when carefully prepared, at a heat below redness, the solution of such a sulphuret in water contains sulphurous and hypo-sulphurous acids, but no sulphuric acid. (6 Ann. de Ch. et Phys. 322.) The metallic sulphurets, also, are partly changed, by solution, into hydrogureted sulphurets; in proof of which, the affusion of an acid throws down a quantity of sulphur. A distinguishing character, too, of solutions of this kind is, that sulphur is precipitated by passing through them sulphureted hydrogen gas, which acts as a weak acid.

According to Proust, if red oxide of mercury be added to solutions of the kind which have been just described, the sulphureted hydrogen is removed, and what remains is a pure liquid sulphuret, from which acids precipitate sulphur only, without any effervescence. But the existence of liquid compounds of sulphur with alkalies and earths, in which hydrogen is not an essential element, is now justly doubted, though they must be admitted not to be impossible. This subject will be farther discussed in that part of the chapter on metals which will treat of the formation and constitution of sulphurets.

SECTION V.

Hydrogen with Selenium.—Selenureted Hydrogen Gas.

Berzelius, by fusing together potassium and selenium, and adding water to the fused mass, obtained a hydro-selenuret of potassa of a deep ale colour. By pouring diluted muriatic acid on the concentrated solution of this compound, a gas is disengaged, which has the following properties.

It has a smell resembling that of sulphureted hydrogen. It is absorbed to a considerable amount by water, which acquires no colour, but after some minutes becomes slightly opalescent, and deposits a little selenium. The solution has an hepatic taste, reddens litmus paper, and gives a permanent brown stain to the skin. Exposed to the air, it is gradually but completely decomposed. It precipitates all metallic solutions when neutral, even those of zinc and iron, generally of a brown or black colour.

This gas produces violent effects on the organs of respiration, and a sharp and painful sensation in the nose, which is followed by the loss, for a time, of the sense of smelling. A small bubble not larger than a pea, when let up into the nostrils, beside the immediate effects which have been described, produced a mucous discharge, which continued fifteen days. (Annals of Phil. xiv. 100.)

To determine its composition, it was transmitted through a solution of acetate of silver, when a selenuret of silver was formed, from the known composition of which Berzelius deduces the composition of this gas to be,

Selenium	97.4	1 atom	41
Hydrogen	2.6	1 do.	1
	100.		42

This determination of the equivalent of selenium, though not exactly agreeing with that deducible from the composition of selenic acid, does not differ more than might be expected from the complicated nature of the process; and we may therefore admit 40 as the true atomic weight of selenium.

Selenium agrees, then, with sulphur and with tellurium, in affording a weak acid when united with hydrogen; an acid which, in all three cases, forms salts with those oxides only whose radicals have a stronger affinity for oxygen than hydrogen has; while it reduces all other oxides, and forms compounds of their respective metals with selenium.

SECTION VI.

Nitrogen with Carbon.

Art. 1.—*Carburet of Nitrogen, or Cyanogen.*

Cyanogen was discovered by Gay Lussac in 1815, while engaged in his excellent researches into the properties of the compound then called *prussiate of mercury*. Its properties have since also been investigated by Vauquelin.

To obtain cyanogen, it is necessary first to boil fine powdered red oxide of mercury with twice its weight of prussian blue and a sufficient quantity of water. The compound is perfectly neutral, and crystallizes in long four-sided prisms truncated obliquely. It still, however, contains a little iron, which may be separated by digesting the liquor, before evaporation, with a little more of the oxide of mercury, and saturating the excess of this oxide with a little prussic acid, or even with a little diluted muriatic acid. The prussiate of mercury, thus obtained neutral and crystallized, must be carefully and completely dried at a temperature below that of boiling water, and then exposed to heat in a small glass retort, or in a tube closed at one extremity. It first blackens, then liquefies, and the cyanogen comes over in the form of a gas, which may be collected over mercury. In the retort there remains a charry matter of the colour of soot, and as light as lamp black. (Gay Lussac, Ann. de Chim. vol. xcv., or Thomson's Annals, viii. 37.)

When produced in sealed glass tubes under pressure, cyanogen was obtained by Mr. Faraday as a liquid, limpid, colourless, and very fluid, not altering its state at 0° Fahr. Its specific gravity was nearly 0.9; its refractive power appeared rather less than that of water. A tube containing it being opened in the air, the expansion within did not appear very great, and the liquid passed slowly into the state of vapour, producing great cold. The vapour, collected over mercury, proved to be pure cyanogen. By the gauge, its force appeared to be equal to no more than 3.6 or 3.7 atmospheres at 45° Fahr.

The properties of cyanogen, collected over mercury, are the following:

1. It is a true gas, or permanently elastic fluid. Its smell is strong, penetrating, and disagreeable. It burns with a bluish flame mixed with purple. Its specific gravity is to that of common air by experiment, as 1.8064; by calculation, as 1.8055, to 1. Hence 100 cubic inches at 60° Fahr. weigh 55 grains.

2. Water at the temperature of 60° Fahr. absorbs almost 4½ times its volume, and pure alcohol 23 times its volume. The watery solution reddens litmus; this, however, is scarcely to be considered as an effect of cyanogen, but of the products to which it gives rise by the decomposition of water. (Vauquelin, in Ann. of Phil. xiii. 430.) By long keeping, a strong solution was found by Vauquelin to assume a light amber colour, and to deposit orange yellow crys-

tals, which he proposes to call *sub-cyanogen*. (Ann. of Phil. N. S. vi. 68.)

3. When 100 measures of cyanogen are detonated, in a Volta's eudiometer, with 250 measures of oxygen gas, 200 measures of carbonic acid result, and 100 measures of nitrogen. There remain, also, 50 measures of oxygen gas uncondensed. From these data, it is deduced by Gay Lussac, that cyanogen is composed of 2 vols. of vapour of carbon, and 1 vol. of nitrogen, condensed into 1 vol. Its density ought, therefore, to be $0.9722 + 0.832 = 1.8042$, a number not very remote from that obtained by experiment.

4. Analysis by more complicated methods affords the same result, coinciding with that in which cyanogen yields, by the action of oxygen, twice its volume of carbonic acid and an equal volume of nitrogen. No water whatsoever is formed during its combustion, if the gas be perfectly free from prussic acid vapour, a sufficient proof of the absence of hydrogen from the composition of cyanogen.

5. Cyanogen and chlorine, both perfectly dry, have no action on each other even in sun-light, and by standing a month; but the presence of moisture modifies the result, and new compounds are formed. (Serullas, 35 Ann. Ch. et de Ph. 299.)

6. Phosphorus, sulphur, and iodine, may be sublimed in it without producing any change; but, when heated in contact with cyanide of mercury, compounds of those bodies with cyanogen are formed. (Davy, Journ. of Science, vol. i.)

7. The solutions of pure alkalies and alkaline earths absorb cyanogen; and the liquid obtained, when poured into a solution of black oxide of iron, affords prussian blue, but not without the addition of an acid. At the same time, carbonic acid gas escapes, in volume equivalent to the cyanogen absorbed, and there is a perceptible smell of prussic acid. These changes will be more evident from the following recapitulation:

1 vol. of cyanogen	= 2 vols. charcoal and 1 vol. nitrogen.	decomposes 1 atom of water,	= 1 vol. oxygen and 2 vols. hydrogen.

One volume of charcoal, uniting with 1 vol. of oxygen, forms 1 vol. of carbonic acid; the remaining volume of charcoal, uniting with ½ vol. of nitrogen and ½ vol. of hydrogen, composes 1 vol. of prussic acid; and the residuary ½ vol. of nitrogen and 1½ vol. of hydrogen compose together 1 volume of ammonia.

ART. 2.—*Hydro-cyanic or Prussic Acid.*

From the *prussiate*, or, more correctly, *ferro-cyanide of mercury*, which has been already described, hydro-cyanic acid may be obtained by distillation with muriatic acid, taking care to employ a proportion of the latter which is not sufficient to saturate the metallic base of the salt. The neck of the retort must be prolonged, for about two feet, by a glass tube of at least half an inch bore, placed horizontally, and containing, in the one-third next the retort, small pieces of white marble, in the other two-thirds, fused chloride of calcium. To the end of this tube a small receiver must be luted, and be kept cool by a freezing mixture. Hydro-cyanic acid, along with muriatic acid and watery vapour, will be disengaged on gently heating the retort, the two last of which will be condensed by the materials in the tube; while the first, by successively heating the different parts of the tube, may be driven onwards to the receiver.

On repeating this process, Vauquelin found the product of hydro-cyanic acid so extremely small, that he was induced to seek for a better method of obtaining it. He succeeded by passing a current of sulphureted hydrogen gas, disengaged from sulphuret of iron and sulphuric acid, very slowly, through a glass tube, slightly heated and filled with cyanide of mercury, its extremity ending in a receiver, which was kept cool by a mixture of snow and salt. The process was carried on till the smell of sulphureted hydrogen, which for a long time could not be perceived, was discovered in the receiver. The hydro-cyanic acid amounted in weight to one-fifth the cyanide of mercury. To avoid any inconvenience from the process being carried too far, some carbonate of lead was placed at the end of the tube next the receiver, in order to absorb the sulphureted hydrogen that might pass undecomposed.

The hydro-cyanic acid is subject to spontaneous decomposition, and the more so the greater its state of concentration. For medical use, into which it has been of late years introduced, it may be obtained by dissolving 60 grains of cyanide of mercury in each ounce of water, and passing a current of sulphureted hydrogen gas through the solution, till the liquid contains a slight excess of it, which may be separated by a little carbonate of lead; after which the fluid may be filtered.

The process adopted at Apothecaries' Hall, London, is the following:—One pound of cyanide of mercury is put into a tubulated retort with six pints of water and one pound of muriatic acid, sp. gr. 1.15; a capacious receiver is luted to the retort; and six pints are distilled over. The specific gravity of the product is 0.995; it must be preserved in bottles excluded from the light, and, being subject to decomposition, should not be long kept. (Brande's Manual, i. 140.) The specific gravity of the acid is considered by Dr. Ure as an inadequate test of its strength; and he recommends the following as a more simple method of analysis: "To 100 grains, or any other convenient quantity, of the acid, contained in a small vial, add, in succession, small quantities of the peroxide of mercury in fine powder, till it ceases to be dissolved on agitation. The weight of the oxide taken up, being divided by four, gives a quotient representing the quantity of real prussic acid present. By weighing out before-hand on a watch glass 40 or 50 grains of the peroxide, the residual weight of it shows at once the quantity expended." (Quarterly Journal, xiii. 312.)

Concentrated hydro-cyanic acid, prepared by the process of Gay Lussac or Vauquelin, is a limpid and colourless fluid. It acts as a quick and virulent poison. It has a great tendency to decompose by keeping. Its taste is at first cool, but soon becomes hot and acrid. Though rectified from chalk, it still reddens litmus paper slightly. Its specific gravity at 45° Fahr. is .7058. It is highly volatile, and boils at 79° Fahr.; at 68° it supports a column of mercury of very nearly 15 inches; and it increases five fold the bulk of any gas with which it is mixed. It congeals at the temperature produced by snow and salt, and liquefies at 5° Fahr. A drop of it placed on paper becomes solid instantly, because the cold, produced by the evaporation of one portion, reduces the temperature of the remainder below its freezing point. Liquid hydro-cyanic acid forms prussian blue directly, both with iron and its oxide, and without the presence of either acid or alkali. The explanation of this fact will be given hereafter. It does not prove, as Vauquelin supposes, that prussian blue is a hydro-cyanate of iron.

Hydro-cyanic acid may also be collected in a gaseous form over mercury, by heating in a retort the crystallized ferro-cyanate of potassa with dilute sulphuric acid. This gas is absorbable by water and alcohol. It is speedily fatal when received into the lungs of small animals. At a temperature between 86° and 95° Fahr., the acid gas forms with oxygen gas a mixture which detonates on passing an electric spark. A quantity equal to 100 measures condense 125 measures of oxygen, and there result 100 measures of carbonic acid and 50 measures of nitrogen. But as the carbonic acid contains only its own volume of oxygen, there remain 25 measures of the latter gas, which must have been converted into water by 50 measures of hydrogen existing in the prussic acid vapour. From these and other facts, Gay Lussac infers that it is composed of 1 volume of the vapour of charcoal, half a volume of hydrogen, and half a volume of nitrogen, condensed into 1 vol.

When liquid hydro-cyanic acid is poured into a vessel filled with chlorine gas, and this is removed into a dark place, an immediate and vivid action takes place; muriatic acid and ammonia are formed, and compose a white solid, and carbonic acid and carbonic oxide are produced. Solid compounds of chlorine, carbon, and hydrogen, appear also to be formed, which require further investigation. (Serullas.)

When potassium is heated in hydro-cyanic vapour, it evolves hydrogen gas equal to half the volume of the vapour. The other elements of the gas unite with the potassium. Thus the hydro-cyanic acid is resolved into hydrogen and cyanogen, which last, uniting with the potassium, forms a cyanide of that metal. As hydro-cyanic acid is constituted of equal volumes of those two gases, united without condensation, we have

$$\begin{array}{l} \text{2 vols. hydro-cyanic} \\ \text{acid vapour} = \end{array} \left\{ \begin{array}{l} \text{1 vol. hydr.} \\ \text{1 vol. cyanog.} = \end{array} \right. \begin{array}{l} = \\ \end{array} \left\{ \begin{array}{l} \text{2 vols. carbon.} \\ \text{1 vol. nitrog.} \end{array} \right.$$

To learn the specific gravity of hydro-cyanic vapour, we must add the sp. gr. of cyanogen to that of hydrogen and divide by 2 (1.8055 + 0.0694 = 1.8749 ÷ 2 = .93745). This differs very little from .9476, the result of experiment. By weight it consists of

Cyanogen - - - - - - - - - - -	100
Hydrogen - - - - - - - - - - -	3.846

or 2 atoms of charcoal = 12, + 1 of nitrogen = 14, + 1 of hydrogen; and its equivalent number is 27.

The salts formed by the union of this acid with salifiable bases are called *hydro-cyanates*, but they are not permanent, and have no useful properties. They are decomposed by the weakest acids, such as the carbonic.

Hydro-cyanate of ammonia crystallizes in cubes or in very small prisms. Its volatility is such, that, at a temperature of 72° Fahr. its vapour supports a column of upwards of 15 inches of mercury; and at 97° Fahr. it is equal to the pressure of the atmosphere. Dr. Thomson finds that, when prussian blue is exposed to a red heat in a copper tube, and the products received over mercury, the glass receiver is coated with transparent crystals of this salt. The solution of this salt precipitates several metallic solutions not affected by hydro-cyanic acid, which, according to Scheele, acts only on nitrates of silver and mercury, and on carbonate of iron. (Ann. of Phil. xv. 394.)

Art. 3.—*Cyanous and Cyanic Acids.*

A peculiar acid was first obtained in a state of combination, by Wöhler, who caused a watery solution of baryta, at the bottom of which were undissolved crystals of that earth, to absorb cyanogen. The barytic salt was decomposed by mixing its solution with one of an alkaline sulphate. (Quart. Journ. xiv. 422, xvi. 104.) He has since obtained the cyanate of potassa, directly, and in great abundance, by the following process: Calcine, at a low red heat, (for a strong heat destroys the cyanic acid) equal weights of anhydrous ferro-cyanate of potassa and peroxide of manganese. Pulverize the remaining mass, and boil it with alcohol 86 per cent. pure; on cooling, the salt separates in small plates resembling the chlorate of potassa. (Ann. de Ch. et de Phys. xxvii. 196.)

The acid, thus obtained in combination with potassa, may be transferred by double decomposition to other bases; but it has not yet been exhibited in a separate state. To this, the easy disunion of its elements by other chemical agents, and even by an increased temperature, is a powerful obstacle. When cyanate of potassa in solution is merely heated, the cyanic acid is decomposed, and carbonic acid and ammonia are generated; and still more readily if a weak acid be added. This property served as the groundwork of a method of analysis, by which Wöhler determined cyanic acid to consist of

Carbon 2 atoms	12
Nitrogen 1 atom	14
Oxygen 1 atom	8
Weight of its atom	34

or of

Cyanogen 1 atom	26
Oxygen 1 atom	8
Weight of its atom	34

It is remarkable that this is precisely the constitution assigned by Liebig and Gay Lussac to cyanic acid as it exists in a class of salts, to which they have given the name of *fulminates*, to be described in vol. 2d., section "On Silver." Liebig, indeed, on re-examining the acid described by Wöhler, has been led to conclude that it is less oxygenated than the true cyanic acid, and that it consists, in fact, of an atom and a half of cyanogen and an atom of oxygen. (35 Ann. de Ch. et de Ph. 334.) But Wöhler, on repeating his analysis, still finds additional evidence of the correctness of his former results, and that the acid, formed by his process, is, as to its proportions of cyanogen and oxygen, precisely analogous to that existing in the fulminating compounds. In preparing these, by the action of silver or mercury on nitric acid and alcohol, a new acid is formed, which may be transferred from the oxides of those metals to other bases. Potassa, for instance, digested with fulminating silver, forms a crystallizable and detonating *fulminate*. In all salts of this kind, the elements of cyanic acid exist, constituting, with a metallic oxide, which may differ in different cases, the acid that gives to each salt its peculiar properties. Beside the metallic oxide, entering as an element into the *fulminic acid*, the fulminating salt contains another portion either of the same or of a different oxide, which serves as a base. The fulminic acid has not, however, any more than the cyanic, been obtained separate; for when this was attempted, either the fulminates were not decomposed by the acids added with that view, or the fulminic acid was resolved into its constituent principles, which, with the elements of the decomposing acid, formed new compounds. When muriatic acid, for instance, was made to act on fulminate of silver, an acid compound was formed of chlorine, carbon, and nitrogen, which, among other peculiar properties, had that of changing the colour of per-chloride of iron to a deep red. (Ann. de Ch. et de Phys. xxiv. 294, xxv. 285.) In the course of his inquiries, Liebig discovered that cyanic acid, uniting with ammonia, composes *urea*, the characteristic ingredient of urine.

Serullas, in an able memoir published in the Ann. de Ch. et de Ph. for August, 1828, admits the existence of an acid composed, as stated by Wöhler, of an atom of cyanogen + an atom of oxygen, but he is disposed to consider this as *cyanous acid*. From the perchloride of cyanogen, which will presently be described, he obtains, by the action of hot water, both muriatic acid, and a new acid compound of cyanogen and oxygen. Evaporation expels the muriatic acid, and leaves a true cyanic acid, capable (which the acid of Wöhler is not) of existing in a separate form, and possessing, indeed, considerable stability of composition, since it affords crystals which may be repeatedly dissolved and recrystallized, and which even dissolve without change in nitric and sulphuric acids. With bases it forms a distinct class of salts properly called *cyanates*. Carefully analyzed, this acid was found to consist of

Cyanogen	1 atom	= 26
Oxygen	2 atoms	= 16
Atomic weight		42

ART. 4.—*Chloro-cyanic Acid (Cyanide of Chlorine, or Chloride of Cyanogen.)*

Chloro-cyanic acid was discovered by Berthollet, who found that hydro-cyanic acid, by absorbing chlorine, acquires new properties, and no longer forms a blue precipitate with the solutions of iron. Supposing the new compound to result from the union of oxygen with the prussic acid, he gave it the name of *oxy-prussic acid*. The nature of this combination has since been investigated by Gay Lussac. (Ann. de Chim. vol. xcv.) To prepare it, a current of chlorine gas may be passed through a solution of hydro-cyanic acid in water, till the liquid decolours the solution of indigo in sulphuric acid. By agitating this liquid with mercury, and by distilling at a gentle heat, an elastic fluid is formed. This, however, is not pure chloro-cyanic acid, for at temperatures from 60° to 70° Fahr., and under common pressures, that acid can only exist as a liquid. It is a mixture of carbonic acid and chloro-cyanic acids, in proportions not yet determined.

The mixture of carbonic and chloro-cyanic acids is colourless; it has a very penetrating smell, and excites a flow of tears; its density, determined by calculation, is 2.123, air being 1. It reddens litmus, is not inflammable, and does not detonate by passing an electric spark through a mixture of the gas, with twice its volume of hydrogen or of oxygen; but, with a mixture of the two, it burns vividly, with the production of a blueish white flame, and of an extremely dense white vapour, which has the smell of nitrous gas, and the taste of a mercurial salt.

A characteristic property of this acid is, that with the intervention of potassa, it forms green precipitates from solutions in which the iron is oxidized to a minimum. The experiment only succeeds when we first add the chloro-cyanic acid to the metallic solution, then a little alkali, and finally a small portion of acid.

According to the analysis of Gay Lussac, this acid is constituted of

$$\left.\begin{array}{l}1 \text{ vol. of gaseous carbon}\\ \tfrac{1}{2} \text{ a volume of nitrogen}\\ \tfrac{1}{2} \text{ ——————— chlorine}\end{array}\right\}\begin{array}{c}\text{condensed into}\\ \text{1 volume.}\end{array}$$

In other words, 1 vol. of chlorine and 1 vol. of cyanogen produce, by combining, 2 vols. of chloro-cyanic acid. Hence its density should be the mean of those of its components.

The compound of cyanogen and chlorine, however, not having been obtained by M. Gay Lussac in a state of purity, M. Serullas has carefully re-examined its formation and properties. (Ann. de Ch. et de Ph. July and August, 1827.) Having found that iodine and bromine, by simple contact with cyanide of mercury, attract cyanogen, Serullas had recourse to the same method of proceeding with the chlorine gas. In the dark, and when the mercurial salt is dry, no change ensues, as M. Gay Lussac had experienced, nor does any very decided change take place, even in sun-light; but the addition of sufficient water to render the cyanide semi-fluid, causes a new combination. In seven or eight hours, even in the dark, the chlorine is found deprived of its colour, and is replaced by a gas not absorbable by mercury, but immediately absorbed by water; in fact, by a true cyanide of chlorine, while the mercury, deserted by the cyanogen, has formed, with another portion of chlorine, bichloride of mercury. The newly-formed gas is not free from atmospheric air, and a small portion of muriatic acid and cyanogen gases; but admits of being purified by its remarkable property of crystallizing by a cold of 0° Fahr. The crystals, as first formed, required to be purified by a series of manipulations, for which, as they would lead me too much into details, I refer to Ann. de Ch. et de Ph. for July, p. 296.

Cyanide of chlorine has a striking analogy, as to its characters and properties, with the similar compounds of iodine and bromine. It remains solid at 0° Fahr., but becomes fluid between + 10 and 5 of the same scale, and at + 68° Fahr. is a gas equivalent to four atmospheres.

It has the form of elongated transparent prisms. Its taste is exceedingly caustic, and it is an active poison. It is decomposed by contact with pure alkalies. Its solution, mixed with potash, and then added to acid sulphate of iron, evolves no green colour; but, if we commence with sulphate of iron, then add potassa, and lastly an acid, the change to green takes place.

The constitution of cyanide of chlorine seems to be

Chlorine, 1 atom - - - - - - - -	36
Cyanogen, 1 atom - - - - - - - -	26
	62

By the action of moistened cyanide of mercury on chlorine, a portion of yellow liquid is also formed, which Serullas believes to be a compound of proto-chloride of carbon and chloride of azote. In this, the explosive property of the latter compound is entirely suppressed, and it is decomposed by an elevated temperature, and by other causes, without any violent phenomena.

Per-chloride of Cyanogen.

We are indebted to Serullas for the discovery of a new compound of chlorine and cyanogen, to which he has given the above name. It is produced by pouring about 15.5 grains of the pure hydrocyanic acid of Gay Lussac into a bottle containing about 61 cubic inches of dry chlorine. The bottle being closed with a stopper, and exposed to sun-light, the hydro-cyanic acid is vapourized; and, after a few hours, a colourless liquid is seen on the inner surface of the bottle, having the appearance of water, which becomes thicker and thicker, and finally, in about twenty-four hours, sets into a white solid, mixed with shining crystals. The process is one of some delicacy, and requires the observance of several precautions, which are given at length in the original memoir. (Ann: de Ch. Aug. 1828, p. 372.)

When carefully purified and dried, it is brilliantly white, and crystallizes in needles; it exhales a vapour, which excites tears. Its specific gravity is 1.320; it fuses at 140°, and boils at 190°. When kept some time it exhales, on opening the bottle, an odour of muriatic acid. It is sparingly soluble in cold water, but dissolves in hot, though with partial decomposition. It is extremely poisonous: a single grain proved fatal to a rabbit.

Potassa, added to the watery solution, causes the formation of muriate and cyanate of that base. Potassium, mixed with the dry per-chloride, combines with it with flame, and chloride and cyanide of potassium are formed. When nitrate of silver is mixed with the watery solution, chloride of silver is precipitated; and cyanate of silver is formed, but remains dissolved by the nitric acid. On cautiously adding ammonia, the chloride is dissolved, and the cyanate is precipitated; but the latter is also dissolved by an excess of ammonia.

All the analytical experiments, made to ascertain its composition, concur in proving it to consist of

Chlorine, 2 atoms - -	72
Cyanogen, 1 atom - -	26
Weight of its atom	98

Art. 5.—*Cyanide of Iodine, and Cyanide of Bromine.*

Cyanide of Iodine.—This compound was obtained by M. Serullas by heating, in a wide-mouthed phial, a mixture of one part iodine and two parts cyanide of mercury, both perfectly dry. When the cyanide of mercury begins to be decomposed, and the violet vapour of iodine ceases to be produced, the phial is placed inclined under an inverted bell-shaped glass, the mouth of which is then closed with a piece of paper or disk of glass. White vapours arise from the phial, and are condensed in fine cotton-like flocks on the surface of the paper or glass disk. To purify these from some adhering cyanide of mercury, they are re-sublimed, at the gentlest heat adequate to that effect.

The cyanide of iodine, thus purified, is perfectly white, and in the form of fine long needles. Its smell is pungent, and it irritates the eyes, producing a flow of tears. Its taste is excessively caustic; its specific gravity such that it sinks in sulphuric acid; it is soluble in water, and still more in alcohol; its solutions are colourless, and have the odour and taste of the substance itself; they neither change the colour of litmus nor turmeric. In this respect the analogy between chlorine and iodine fails, for the compound of the former with cyanogen is decidedly acid; while that with the latter has no acid properties.

Solution of pure potassa decomposes this substance, and hydriodate and hydro-cyanate of that base are formed. The solution affords a beautiful green precipitate with proto-sulphate of iron. Nitric acid dissolves it entire. Muriatic acid resolves it into hydro-cyanic acid and iodine. Sulphurous acid decomposes it suddenly, a few drops of the watery solution instantly disengaging iodine from the crystals; but the gas itself has not, if dry, any action upon them.

By an analysis of this substance, M. Serullas determined it to be a compound of

1 atom of iodine - -	125
1 atom of cyanogen -	26
	151

Cyanide of bromine has been obtained by M. Serullas, by a process analogous to that for preparing cyanide of iodine. The properties of the three cyanides (of chlorine, iodine, and bromine) resemble each other so closely, that for a description and analysis of the last, I think it sufficient to refer to the original memoirs in the 34th and 35th vols. of Ann. de Ch. et de Phys.

ART. 6.—*Of Sulpho-cyanic Acid.*

This acid was discovered by Mr. Porrett, to whom we are indebted for a number of curious and interesting experiments on all the acids having cyanogen for their base. He gave it the name of *sulphureted chyazic acid*, the term chyazic being compounded of the first letter of carbon, the first syllables of hydrogen and azote, with the usual termination signifying an acid. He considered it as a compound of sulphur with hydro-cyanic acid, but since the researches of Gay Lussac, it may be rather regarded as a compound of sulphur with cyanogen.

The original process of Mr. Porrett is somewhat complicated and tedious. The following method was contrived by Grotthus, and improved by Vogel. Mix equal weights of pulverized ferro-cyanate (commonly called prussiate) of potassa and flowers of sulphur, and expose the mixture in a flask to a heat sufficient to melt the sulphur, keeping it melted for several hours. When cold, reduce the mass to powder, and digest it in water enough to take up every thing soluble. Filter the liquor, and drop into it a sufficient quantity of potassa to precipitate any iron that may be held in solution. The liquid, thus prepared, is a solution of sulpho-cyanate of potassa in water, and the acid ingredient may be obtained, mixed with water, by distilling it with sulphuric acid.

Sulpho-cyanic acid, thus obtained, is a transparent liquid, colourless, or with a slight pinkish hue, with an odour as strong as, and somewhat resembling, that of acetic acid. The strongest obtained by Mr. Porrett had the specific gravity 1.022. It dissolves a little more sulphur at a boiling temperature; but most of this is separated again on cooling. In this state it throws down oxide of silver from the nitrate of a dark colour; but otherwise the precipitate is white.

Sulpho-cyanic acid boils at 216½°; and at 54½° crystallizes in six-sided prisms. When thrown into a red-hot platinum crucible, sulphur is disengaged, and a blue flame is produced. It is partially decomposed by being transmitted through a red-hot porcelain tube; and, if brought into contact with ignited iron turnings, sulphuret of iron is formed, and hydro-cyanic acid and sulphureted hydrogen disengaged.

By a sufficient quantity of chlorine, the whole of the sulphur is converted into sulphuric acid, and hydro-cyanic acid is disengaged. Iodine produces a similar effect.

When added to solutions of the per-salts of iron, it changes them to a deep red colour. With protoxide of copper, it affords a white insoluble sulpho-cyanate. From the analysis of this salt, Mr. Porret drew his inference respecting the composition of the acid, which he conceived to consist of one-third by weight of the elements of hydro-cyanic acid, and two-thirds of sulphur. According to Dr. Thomson (System, 6th edit. ii. 306), it is constituted of

2 atoms of sulphur	32
2 atoms of charcoal	12
1 atom of nitrogen	14
1 atom of hydrogen	1

If this be the correct view, its equivalent number is 59

It is capable of uniting with salifiable bases, and composes a genus of salts called *sulpho-cyanates.* Many of these have been investigated by Mr. Porrett.

ART. 7—*Ferro-cyanic Acid.*

The ferro-cyanic acid may be prepared by the following process: dissolve in cold water any quantity of the salt called triple prussiate (ferro-cyanate) of baryta, and for every ten grains so dissolved, add a quantity of sulphuric acid equivalent to 2.53 grains of real acid; stir the mixture; and set it aside for some time. The baryta and sulphuric acid are precipitated in combination; and the ferrocyanic acid may be decanted for use. Its characters are the following:

It has a pale lemon-yellow colour; has no smell; and is not poisonous in small quantities. It is decomposed by a gentle heat, or by exposure to a strong light, in which case hydro-cyanic acid is formed, and also white triple prussiate of iron, which, by absorbing oxygen, becomes prussian blue. With alkalies, earths, and metallic oxides, it forms directly the salts called *triple prussiates.* It displaces acetic acid from all its combinations, and also detaches, from other acids, those bases, with which it is susceptible of forming compounds that are insoluble in acids. Being decomposable by heat, it can never be obtained by distillation. In that case, hydrocyanic acid and hydro-cyanate of iron are formed. Mr. Porrett has also pointed out a method of obtaining ferro-cyanic acid in a crystallized form. Dissolve 58 grains of crystallized tartaric acid in alcohol, and 50 grains of ferro-cyanate of potassa in as little warm water as possible. Mix the two liquids. Bi-tartrate of potassa is precipitated, and the ferro-cyanic acid remains in solution. By spontaneous evaporation, it crystallizes in small yellow cubes, which, on exposure to the light, lose their regular shape, are decomposed, and become coated with prussian blue. It appears, therefore, that the balance of affinities, preserving this acid, is very soon disturbed, and that its elements are easily thrown into new arrangements.

We are indebted to Mr. Porrett for the view, which is most commonly taken of the nature of the acid entering into the composition of the salts formerly called *prussiates* or *triple prussiates*. It had generally been supposed that the protoxide of iron, which is always present in these salts, acted the part of a base, with which (conjointly with an alkali or earth) the prussic acid was supposed to be united in the triple compounds. Mr. Porrett, however, has rendered it more probable that the oxide is really an element of the acid, and not a base; for he finds that when triple prussiate of soda in solution is exposed to galvanic electricity, the oxide of iron is carried, along with the elements of the prussic acid, to the positive pole: whereas, if it had existed as a base, it would have been determined to the negative pole. He proposed for it the name of *ferrureted chyazic acid;* but I prefer that of ferro-cyanic, which, not necessarily excluding hydrogen from its composition, is still consistent with the new view arising out of Mr. Porrett's researches. This view explains why the iron in triple prussiates (ferro-cyanates) is not discoverable by the most delicate tests, for it can no more be affected by them, than sulphur can be indicated by its appropriate tests when existing in sulphuric acid.

According to the latest analysis by Mr. Porrett, ferro-cyanic acid consists of 1 atom of hydro-cyanic acid + 2 atoms of charcoal + 1 atom of metallic iron. M. Robiquet, on the other hand, regards it as compounded of the elements of hydro-cyanic acid and of *cyanide* of iron, in the same manner as we may conceive alcohol to be formed of water and olefiant gas. (Ann. de Ch. et de Phys. xvii. 197.) He considers it, indeed, as a true hydracid, and in this opinion Gay Lussac coincides, assigning to it the following constitution. (Same work, xxii. 322.)

2 atoms of hygrogen	2
1 atom of iron	28
3 atoms of cyanogen	78
	108

or of

2 atoms hydro-cyanic acid	54
1 atom cyanide of iron	54
	108

The radicle of the acid then is formed of 1 atom of iron, and 3 atoms of cyanogen. When we unite the acid with an oxide, its hydrogen forms water with the oxygen of the oxide, and its radicle combines with the metallic base of the latter. The compound obtained is, therefore, no longer a prussiate or ferro-cyanate, but a *ferro-cyanide.* Again, when we act upon this last compound with a hydracid (sulphureted hydrogen for instance) its hydrogen unites with the iron and cyanogen, and regenerates *hydro-ferro-cyanic* acid, which, under this view, is the proper appellation of ferro-prussic acid.

Berzelius, in his former paper, did not admit the existence of such an acid as the ferro-cyanic; but in a recent work on Iron, quoted by Mr. R. Phillips (Ann. of Phil. &c. for February, 1827, p. 113), he says, that ferruginous hydro-cyanic acid (*l'acide hydro-cyanique ferruginè*) is composed either of

Prussic acid - - - - - - - - -	46.57
Prussiate of protoxide of iron - -	53.43
	100.

or of

Prussic acid - - - - - - - - -	46.57
Cyanide of iron - - - - - - - -	45.77
Water - - - - - - - - - - - -	7.66
	100.0

On the former view the water obtained by heating the triple prussiate, is formed by the union of the hydrogen of the hydro-cyanic acid and the oxygen of the oxides; on the latter it is merely separated. From the facts which are at present known, it cannot be decided which is the true view, and farther experiments are necessary to throw light on this obscure subject.

SECTION VII.

Compounds of Phosphorus.

ART. 1.—*Phosphuret of Sulphur.*

Phosphorus is capable of uniting with sulphur in various proportions; but it is probable that the most energetic compound would be obtained by taking the two substances in quantities indicated by the weights of their atoms, *viz.*, 16 parts of sulphur to 12 of phosphorus. The process requires some caution, to prevent accidents by the explosion of the melted substances; and it is advisable not to operate on more than from 60 to 80 grains of the materials taken together. The combination may be effected either under water or not. In the first case, the phosphorus and sulphur may be put together into a tube containing water, the temperature of which should not exceed from 140° to 160° Fahr., and the tube may be agitated till the combination has taken place. In the second case, into a tube 4 or 5 inches long, and from 4-10ths to 8-10ths of an inch wide, the phosphorus may be put first, and, when fused by the heat of a lamp, the sulphur may be added at intervals in small fragments. In both cases, sulphureted hydrogen is evolved at the moment of combination.

The phosphuret of sulphur is much more fusible than phosphorus itself, its melting point being about 41° Fahr. Hence it is fluid at the common temperature of the atmosphere. It has a reddish brown colour when fresh prepared, but this may be removed by shaking it with a solution of ammonia, and leaving it some hours under that liquid. At common temperatures it does not act at all on water, nor does it decompose water rapidly even at 212° Fahr. A compound, prepared by Mr. Faraday from 5 of sulphur and 7 of phosphorus, did not become solid at 20° Fahr., and was perfectly fluid at 32°. On remaining some weeks under water, it deposited crystals of pure sulphur, and a compound remained that was not so fusible as the original one.[*]

ART. 2.—*Phosphuret of Selenium.*

Selenium is speedily dissolved by melted phosphorus, and, if added to saturation, a very fusible compound results, which, when cold, has a dark brown colour, much lustre, and a vitreous fracture. When this compound is digested in water, seleniureted hydrogen is formed, which, dissolving in the water, communicates to it a peculiar hepatic odour. The proportions of its constituents are unknown.

SECTION VIII.

Compounds of Sulphur with Carbon, Selenium, &c.

The compounds of sulphur with hydrogen having been already described, the only ones that remain are those which sulphur forms with carbon and with selenium.

ART. 1.—*Bi-sulphuret of Carbon, or Alcohol of Sulphur.*

There has been much controversy respecting the nature of this compound; and several contradictory statements have been given of its composition. It was discovered by Lampadius in 1796, and was considered by him as consisting of sulphur and hydrogen. Clément and Desormes were led, by their researches, to deny the presence of the latter element; and to conclude that it is a compound of sulphur and charcoal only. This inference was afterwards controverted by Vauquelin and by Berthollet, jun.; and the experiments of Cluzel also were supposed by their author to be favourable to the opinion, that it contains hydrogen. (Ann. de Chim. lxxxiv. 73.) In a report, however, on the Memoir of Cluzel, MM. Berthollet, sen., Thenard, and Vauquelin, described a set of experiments made by the last-mentioned chemist, which led them to believe that the alcohol of sulphur is a compound of sulphur and charcoal only; (Ann. de Chim. lxxxiii. 252;) and this inference has been proved to be correct, by the subsequent investigation of Berzelius and Marcet. (Phil. Trans. 1818.)

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[*] Quarterly Journal, iv. 361. See also Pelletier, Ann. de Chim. iv. 10; and Accum and Briggs, Nicholson's Journal, vi. and vii.

To prepare this substance, a coated earthen tube, of about one inch and a half in diameter, partly filled with small pieces of charcoal, well prepared and quite free from moisture, may be disposed in a furnace, as represented fig. 40, *c c*, one end being placed higher than the other. To this extremity may be adapted a glass tube, open at both ends, containing small bits of sulphur; and to the other end, by means of an adopter, is to be fixed a curved tube, passed into water contained in a two-necked bottle. The part of the tube, containing the charcoal, may then be made red-hot; and, when this happens, the bits of sulphur are to be pushed forwards, one by one, by means of a wire, carefully excluding atmospheric air. As soon as the sulphur comes into contact with the charcoal, bubbles of gas will be produced in great abundance, and a vapour will appear, which will condense under the water in the bottle, into a liquid, of which, in the course of a day, about half a pint may be procured. This liquid may be purified by redistilling it at a very gentle heat, not exceeding 100° or 110° Fahrenheit; and some dry chloride of calcium may be put into the retort, in order to obtain the fluid perfectly free from water. The liquid which comes over is quite pure, and some sulphur remains in the retort. It may also be obtained by distilling a mixture of ten parts of finely-pulverized and perfect charcoal with 50 of native bi-sulphuret of iron, from an earthen retort, into a receiver surrounded by ice or snow. One part of bi-sulphuret of carbon will be obtained from these materials.

The alcohol of sulphur has the following properties:

It is eminently transparent, and perfectly colourless. Sometimes, immediately after distillation, the oily liquid appears a little opaque and milky; but the next day it is found to have become completely limpid. It has an acrid, pungent, and somewhat aromatic taste; its smell is nauseous and fetid, though differing from that of sulphureted hydrogen.

Its specific gravity is 1.272; its refractive power, as ascertained by Dr. Wollaston, is 1.645. Its expansive force (at 30 inches barometer, and 53½° Fahrenheit) is equal to the pressure of 7.36 inches of mercury; so that air, to which it is admitted, will dilate about one-fourth of its volume. It boils briskly under the common atmospheric pressure, at a temperature of 105° or 110° Fahrenheit. It does not congeal, even at a temperature so low as 60° below 0 of Fahrenheit.

Bi-sulphuret of carbon has an extraordinary power of producing cold by its volatilization. The bulb of a thermometer being covered with fine lint, and moistened with a few drops of the liquor, the mercury sinks rapidly from 60° to 0; and under the exhausted receiver of an air-pump (the valves of which must, for this purpose, be made of metal, and not of silk) it falls from + 70°, to 70° or even 80° below 0°, so that by this process mercury may readily be frozen. (Marcet.) It has been found, also, by Mr. Murray, that when a few drops of this liquid are poured on the surface of a glass of water, the temperature of which is 32° Fahr., plumose branches of ice dart from the sulphuret to the bottom of the vessel, and the whole water is suddenly frozen. At the same time, the sulphuret becomes volatilized; and the spiculæ of ice beautifully exhibit the colours of the solar spectrum. (Ann. of Philos. iii. N. S.)

It is highly inflammable, and takes fire at a temperature scarcely exceeding that at which mercury boils. Its flame is bluish, and it emits copious fumes of sulphurous acid. If a long glass tube, open at both ends, be held over the flame, care being taken to keep the tube quite cool, no moisture whatever is deposited on its inner surface—a sufficient proof of the absence of hydrogen.

It is decomposed by contact with chlorine, and chloride of sulphur is obtained.

The oily liquid readily dissolves in alcohol and ether, though not in all proportions, and these solutions are decomposed by the addition of water. It easily incorporates with fixed and volatile oils, and rapidly dissolves camphor. It is not soluble in water, but when shaken with it separates again on standing.

In its liquid state, it suffers no change on being heated with potassium; but potassium, when heated in its vapour, becomes ignited, and emits a reddish flame. The residue, when washed with water, affords charcoal and hydro-sulphuret of potassa.

It does not tarnish mercury or its amalgams, nor silver, unless it contains more sulphur than is essential to its constitution.

The alkalies dissolve it entirely, but very slowly. Of the acids, none exert any sensible action on it.

When transmitted over ignited copper or iron turnings, alcohol of sulphur is decomposed, the metal combining both with charcoal and sulphur; and a rose-coloured fluid is obtained, differing in its sensible qualities from the original liquid, and apparently consisting of the same elements in different proportions. It is decomposed also when brought into contact with ignited per-oxide of iron; sulphuret of iron is formed; and sulphurous and carbonic acids are produced, and may be separated from each other by borax, which absorbs the former only. In this way it may be analyzed, and its proportions calculated.

The proportions of the elements of sulphuret of carbon are deduced by Berthollet, Thenard, and Vauquelin, to be from 14 to 15 parts of charcoal, and from 85 to 86 of sulphur, in 100. This statement of its composition agrees with the results of Berzelius and Marcet; *viz.*,

Sulphur - 84.83 - or - 32 = 2 atoms
Carbon - 15.17 - or - 6 = 1 atom
100. Atomic weight 38

The bi-sulphuret of carbon was found by Berzelius, who has given it the name of *sulfide carbonique*, to be capable of uniting with alkaline and earthy bases, and of forming compounds which may be called *Carbo-sulphurets*, or as he has recently termed them, (Ann. de Ch. et de Ph. xxxii. 78,) but perhaps less properly, *Sulpho-carbonates*. They are with difficulty obtained pure, on account of the feeble attraction which the carburet of sulphur has for bases. When those with bases of the fixed alkalies are strongly heated in a dry state, they are decomposed, charcoal is separated, and a sulphuret with excess of sulphur of the respective metals remains. Even the temperature, necessary for desiccation, decomposes the greater number, and with phenomena differing with the degree of attraction of the metallic base for oxygen. The colour of the eight alkaline ones, when in solution, is deep orange; their taste hepatic and a little acrid, like that of pepper. Mixed in a solid state with an acid, the muriatic for instance, they give the oily red liquid discovered by Zeise.

By the action of a mixture of fuming muriatic acid on bi-sulphuret of carbon, Berzelius obtained a solid white crystalline body, resembling camphor, and possessing some remarkable properties. Its analysis afforded

Muriatic acid - - - - 48.74
Sulphurous acid - - - 29.63
Carbonic acid (and loss) - 21.63
100.

These proportions agree best with two atoms of muriatic acid, one of sulphurous acid, and one of carbonic acid.

New Acid (the Hydroxanthic, or Carbo-sulphuric) produced by the Action of Alkalies on Bi-sulphuret of Carbon.

When bi-sulphuret of carbon is gradually added to a solution of pure potassa, in alcohol = 96 or 98 per cent. pure, and the mixture is agitated, the alkali is completely neutralized by the formation of a new acid. This new acid contains sulphur, carbon, and hydrogen, the two first of which probably form a compound base, analogous to cyanogen, and, like it, acidifiable by hydrogen. To the base, M. Zeise, Professor of Chemistry at Copenhagen, who first noticed these facts, has given the name of *xanthogene* (from ξανθος, yellow, and γενναω, to generate), on account of the yellow colour of its compounds; and to the acid, that of *hydroxanthic acid.*

The neutral solution, obtained in the above manner, may be made to deposit crystals by lowering its temperature to the freezing point, or by exposing it under an exhausted receiver along with sulphuric acid. These crystals are the *hydroxanthate of potassa.* They are needle-shaped; without colour, except after exposure to the air, which renders them yellow; have a peculiar odour; a taste at first cooling, and then sharp and sulphurous; are extremely soluble in water, though not deliquescent; in a less degree in ether; and not at all in naphtha. The watery solution becomes milky when exposed to the air, and soon manifests an excess of alkali. Sulphuric or muriatic acid, diluted with four or five parts of water, and added in due quantity to the watery solution, occasions no effervescence, but causes the separation of an oily-looking fluid heavier than water. This is the *hydroxanthic acid.*

Solution of baryta in water or in acids, muriate of lime, and sulphates of magnesia or alumina, do not affect the hydroxanthate of potassa; but several metallic salts occasion precipitates which are compounds not of the metallic oxides with the new acids, but of the metals with xanthogen. Hence M. Zeise proposes to call them *xanthures;* but it is more consistent with the nomenclature followed in this work to term them *xanthides*, analogous to *chlorides*, *cyanides*, &c. Several of these xanthides he has described in his memoir.

The *hydroxanthate of potassa* is decomposed when distilled *per se*, and yields an oily fluid, with a gas which has the smell of onions, but in which nothing could be discovered but carbonic acid and sulphureted hydrogen. At a red heat, in the open air, it takes fire, and is consumed tranquilly with a bluish flame, but in the flame of a candle it burns actively, emitting bright sparks.

Hydroxanthates of soda and ammonia may be prepared with alcoholic solutions of those alkalies and bi-sulphuret of carbon; those of baryta and lime with hydroxanthic acid and their respective carbonates. The salt, with base of soda, is a little deliquescent.

Hydroxanthic acid, separated by more powerful acids from its saline compounds, with some precautions which M. Zeise has pointed out, is liquid at common temperatures, and even below them; it has the aspect of a transparent colourless oil; in specific gravity it exceeds water; and it is not miscible with that fluid. Exposed to the air, it soon becomes covered with a white opaque crust. Its smell is powerful and peculiar. It has a taste at first acid, then astringent and bitter; litmus paper is completely reddened by it, but a part of the paper soon changes to a yellowish white. It is inflammable, and burns with a smell of sulphurous acid. A temperature below 212° decomposes it into bi-sulphuret of carbon and a combustible gas. When much divided by agitation with water, it is decomposed in a short time, giving out bubbles of gas. It expels carbonic acid from alkaline carbonates. The oxides of common metals (copper, lead, mercury, &c.) decompose it by giving up their oxygen to the hydrogen of the acid, and the xanthogene unites with the metal, forming *xanthides.*

The presence of hydrogen in hydroxanthic acid was established by the results of acting upon it with iodine, which occasioned a distinct production of hydriodic acid, a compound of iodine and hydrogen. (Ann. de Chim. et de Phys. xxi. 160, and Ann. of Phil. N. S. iv. 241.)

Action of Ammonia on Bi-sulphuret of Carbon dissolved in Alcohol.

The action of ammonia on the alcoholic solution of bi-sulphuret of carbon is very different from that of potassa. No hydroxanthate is formed; but at least two new salts are produced, the one containing a new acid, which may be considered as a compound of sulpho-cyanic acid and sulphureted hydrogen; the other as containing a double sulphuret of hydrogen and carbon. By this action, the ammonia and the bi-sulphuret both undergo decomposition.

When a mixture of 15 to 17 measures of bi-sulphuret of carbon, 45 of alcohol, and 100 of alcohol saturated with ammonia, are put into a flask which they nearly fill, and which is then closed with a glass stopper, the mixture, left at a temperature from 53° to 57° F., in about ten minutes becomes yellow, and in about 20 minutes brown. Shortly after, a great number of small feathery crystals are perceived, the greater part of which fall to the bottom of the vessel. A flocculent matter also attaches itself to the stopper, and to the parts of the glass which are not covered with liquid, of the same nature as the crystals. This goes on for about an hour or an hour and a half, after which a crystallization of another kind begins; the crystals are more distinctly grouped, often in stars, have more brilliancy, and a distinct prismatic form; they continue to be deposited during 30 or 40 hours, and to increase in size, sometimes to that of half an inch. At the same time the first crop of crystals diminishes in quantity, and sometimes almost disappears.

The salt first deposited is a double sulphuret of carbon and hydrogen united with ammonia. It was called the *reddening salt*, from its property of becoming speedily red by contact with the air, chiefly from the absorption of moisture. This change takes place with such facility, that it is scarcely possible to obtain it otherwise than red, unless the alcohol be removed by washing it with ether, and then by compression in bibulous paper, it may be dried, and will bear exposure to the air for five or six minutes without alteration. It dissolves entirely and readily in water, producing a brown-red solution, from which sulphuric or muriatic acid liberates sulphureted hydrogen. This solution gives a red precipitate with salts of lead, brown with salts of copper, and yellow with those of mercury. All these precipitates change gradually, even when secluded from air; sulphuret of carbon separating, and a metallic sulphuret being left.

The second set of crystals may be obtained apart from the first. by pouring off the liquid as soon as they begin to appear, which is generally in about two hours; filtering it rapidly through paper moistened with alcohol; and leaving it in a closed wide-mouthed flask for ten hours, at a temperature of 50° Fahr. In 30 hours, the liquor may be decanted, the crystals washed with a small quantity of alcohol, and the salt compressed strongly between folds of paper. If intended to be preserved, it may be dried by keeping it, along with sulphuric acid, *in vacuo*. It is nearly without odour, unless it has been exposed to a damp atmosphere; dissolves abundantly in water, but less readily in alcohol; its solution effervesces with those acids only which decompose it, such as the nitric; it is not precipitated by salts with base of lime or baryta, but is precipitated of various colours by metallic salts. Solution of potassa, heated with the yellow precipitate thrown down by per-salts of copper, is neutralized, and the hydro-sulphocyanate of potassa of Porrett is obtained. From the analysis of this yellow precipitate, M. Zeise infers the ammoniacal salt, to which he gives the name of *Hydrosulphureted Hydro-sulphocyanate of Ammonia*, to consist of one atom of ammonia, one atom of hydro-sulphocyanic acid, with two atoms of hydrogen and one of sulphur.

By the action of persulphate or permuriate of iron, added in small portions to a very dilute solution of the ammoniacal salt acidulated with muriatic acid, a snow white crystalline solid is obtained in the form of shining scales, having scarcely any odour, and not changing remarkably by contact with air. This appears to be a *crystallized hydrosulphuret of cyanogen*, and is probably a compound of 1 atom of nitrogen, 2 of carbon, 4 of sulphur, and 4 of hydrogen.

The above is but an imperfect outline of the facts stated by M. Zeise, which, as well as the general reasoning arising out of them, though important and ingenious, are not very susceptible of abridgment. I refer the reader, therefore, to the original memoirs in the Ann. de Chim. et de Phys. xxvi. 66, 113; and to an abstract in the Quart. Journ. xviii. 149.

Sulphuret of Selenium.

One part of selenium, melted with 100 parts of sulphur, imparts to the sulphur a dirty yellow colour; but the only method of obtaining a sulphuret of selenium of determinate composition is to precipitate a solution of selenic acid by sulphureted hydrogen gas, and to wash the precipitate with a little muriatic acid. A deep orange coloured compound is formed, in which 100 parts by weight of selenium are united with 60.75 sulphur. It is attacked with difficulty by nitric acid, but more readily by nitro-muriatic. It is soluble in the fixed caustic alkalies, as well as in alkaline hydrosulphurets, and gives a solution of a deep orange colour. When heated in the air, it burns at first with the odour of sulphurous acid, and then with that of horse-radish. (Berzelius, Ann. of Phil. xiv. 102.)

Sulphuret of Boron.

This compound has been described by Berzelius, whose account of it may be found in the 10th vol. 2d series, of Ann. of Phil. p. 129.

Sulphuret of Cyanogen.

This compound was first formed by Lassaigne. Into a small glass balloon, he puts a little cyanide of mercury finely pulverized, and pours upon it half its weight of bi-chloride of sulphur. At the end of 14 or 15 days of exposure to day-light, the balloon being closed so as to exclude air, a minute quantity of crystals rise to the upper part of the balloon. These crystals have a penetrating odour, and when applied to the tongue, give the sensation of a prick from a sharp point, the part remaining for some time red and painful. They dissolve in water, but more abundantly in alcohol; the former solution reddens litmus paper, the latter not. Like the sulpho-cyanic acid of Porrett, which may possibly be identical with this new compound, the latter forms crimson coloured salts with per-oxide of iron. In a pure state, it forms crystalline plates, not unlike those of chlorate of potassa. It sublimes at common temperatures. By exposure, during some weeks, to light, it becomes, first yellow, and then orange, retaining its chemical properties. Galvanic electricity decomposes it, the cyanogen being attracted by the negative, and the sulphur by the positive pole. Its probable constitution is 1 atom of sulphur + 2 atoms of cyanogen; but this requires verification by future experiments. (Ann. de Chim. et de Ph. Oct. 1828.)

CHAPTER IX.

OF METALS.

Of the General Properties of Metals.

The metals constitute a class of bodies, which are not more interesting from their application to the common arts of life, than from the facts which they contribute to establish the general principles of chemical science. Only seven or eight were known to the ancients; but within the last century, the class has been increased to more than five times that number. The following appear to have a sufficient claim to be considered as distinct metals.

TABLE OF METALS.

Names of Metals.	Discovered by	Date.
1. Gold - - -	Known since the remotest antiquity.	
2. Silver - - -		
3. Iron - - -		
4. Copper - -		
5. Mercury - -		
6. Lead - - -		
7. Tin - - -		
8. Zinc - - - -	Known to Paracelsus, who died - -	1541
9. Bismuth - -	Described by Agricola - - - - -	1520
10. Antimony - -	Described by Basil Valentine, 15th century.	
11. Arsenic - -	Brandt - - - - - - - - - - -	1733
12. Cobalt - -		

Names of Metals.	Discovered by	Date.
13. Platinum	Wood, Assay Master, Jamaica	1741
14. Nickel	Cronstedt	1751
15. Manganese	Gahn and Scheele	1774
16. Tungsten	M. M. Delhuyart	1781
17. Tellurium	Muller	1782
18. Molybdenum	Ditto and Hielm	1782
19. Titanium	Gregor	1781
20. Uranium	Klaproth	1789
21. Chromium	Vauquelin	1797
22. Columbium	Hatchett	1802
23. Palladium	Dr. Wollaston	1803
24. Rhodium		
25. Iridium	Descostils and Tennant	1803
26. Osmium	Tennant	1803
27. Cerium	Hisinger and Berzelius	1804
28. Potassium	Sir H. Davy	1807
29. Sodium		
30. Barium		
31. Strontium		
32. Calcium		
33. Lithium	Arfwedson	1818
34. Magnesium	Sir H. Davy	1807
35. Cadmium	Stromeyer	1818
36. Aluminum	Wöhler	1828
37. Glucinum		
38. Yttrium		

Silicium, generally classed among metals, it will afterwards appear, has but a doubtful claim to be placed among metals, and is by many chemists considered to belong to another class of substances.

Of a class comprehending so many individuals, it is not easy to offer a general description; but it will be found that the metals are all characterized by one or more of the following properties.

1. With the exception of the newly discovered bases of the alkalies and earths, they are distinguished by a high degree of specific gravity, the lightest of the other metals (tellurium) being considerably heavier than the most ponderous of the earths. I omit the Table of Specific Gravities of Metals, given in the former editions of this work, because the sp. gr. of each metal is stated under its particular history, besides being included in the Table at the end of vol. ii.

The metals are, perhaps, the only solid bodies, whose specific gravity is affected by mechanical means, or, in other words, whose particles can be brought permanently into a state of nearer approximation by pressure. In consequence of this property, several of the metals undergo material changes in their specific gravity, by the mechanical operations of rolling, hammering, &c. It may be questioned, whether the metals are heavier than other bodies, in consequence of the greater specific gravity of their individual atoms, or from a greater number of atoms being aggregated into a given volume. The former, however, is most probably the true reason, though it must be acknowledged that their specific gravity is by no means *exactly* proportional to the weights of their atoms.

2. They are opaque, at least in the state in which they generally occur to our observation. Gold, however, beat into leaves $\frac{1}{200000}$th of an inch in thickness, transmits a faint greenish light, when held between the eye and the direct rays of the sun.

3. They possess various degrees of lustre, which is of so peculiar a kind, that it has been termed by mineralogists the *metallic lustre*, and referred to as a known standard in the description of other minerals. Some of the metals possess this property in so remarkable a degree, as to be applicable to highly ornamental purposes. Polished steel takes place of all the metals in the perfection of its lustre; but some of the class (as cobalt and nickel) appear to be susceptible of it in only a small degree.

4. The metals are excellent *reflectors*, not only of light but of caloric; and hence they are the best materials for the composition of burning mirrors. From the experiments of Mr. Leslie, they appear to possess this property in the following order, the highest number denoting the greatest reflecting power.

Brass	100
Silver	90
Tinfoil	85
Planished block tin	80
Steel	70
Lead	60
Tinfoil softened by mercury	50

In general the reflecting power was found, by Mr. Leslie, to be proportionate to the degree of polish, and to be impaired by every thing that diminished this quality. A tin reflector, for example, had its reflecting power diminished nine-tenths by being rubbed with sand-paper.

5. Metallic bodies are, of all others, the best conductors of electricity. Their conducting power, Becquerel finds, increases with their mass, and not with their surface; consequently the electric fluid, when in motion, is not merely carried over the surface, but penetrates the interior. Representing by 100 the conducting power of copper, he has given from experiment, that of ten of the principal metals in the following Table. (Ann. de Ch. et de Ph. xxxii. 428.)

Table of the Conducting Powers of the Metals for Electricity.

Copper	100.0
Gold	93.60
Silver	73.60
Zinc	28.50
Tin	15.50
Platinum	16.40
Iron	15.80
Lead	8.30
Mercury	3.45
Potassium	1.33

When the quantity of metals is great enough to convey away the electricity which seeks a passage, no change is produced in them; but when insufficient, as in very fine wires, the electric fluid heats them, and sometimes fuses and even volatilizes them. In this state of vapour, they burn more or less vividly, and with differently coloured flames; zinc with a white flame mixed with blue and red; tin, bluish white; lead, bluish or purple; and silver, green.

Their properties as *electro-motors* have already been described in the chapter on the chemical agencies of electricity and galvanism.

6. The metals are excellent *conductors of caloric.* The degrees, in which different metals possess this property, are exhibited in a Table in the chapter on caloric.

7. The metals are all *fusible*, provided a due degree of heat be applied, which, for some, is very moderate, and for others extremely intense. Mercury is the only metal that exists constantly in a fluid state at the temperature of our climate. Potassium, sodium, tin, bismuth, lead, tellurium, arsenic, zinc, antimony, and cadmium, all melt at a temperature below that of visible redness, and in the order set down, the most fusible being placed first. Silver, copper, gold, cobalt, iron, manganese, nickel, and palladium, all require a red heat. Molybdenum, uranium, tungsten, and chromium, are almost infusible, and cannot be obtained by the heat of a forge in compact masses, but fuse under the oxygen and hydrogen blow-pipe. Titanium, cerium, osmium, iridium, rhodium, platinum, and columbium, are infusible by the forge, but yield to the powers of the oxygen and hydrogen blow-pipe.

8. One of the most useful properties of the metals is their *malleability*, or capacity of being extended by the blows of a hammer. In this quality, gold takes place of all the rest. The gold leaf, which is sold in books, is so extremely thin, that less than five grains cover a surface of about $272\frac{1}{4}$ square inches; and the thickness of each leaf does not exceed $\frac{1}{282020}$th part of an inch. All the metals, however, are not malleable. Gold, platinum, silver, palladium, mercury in its frozen state, copper, iron, lead, tin, zinc, and nickel, (the last on the authority of Richter,) are the only ones to which this property belongs. The rest, on account of their brittleness, were formerly called *semi-metals.* But since, even in these, a diminishing progression of malleability may be observed, the distinction, though retained in common language, is very properly rejected from chemical and mineralogical systems.

9. All the metals that have been described as malleable (with the exception, perhaps, of nickel,) are also *ductile*, or may be formed into wire. Iron, though so hard a metal, may be drawn into wire not thicker than a human hair. A grain of gold, it has been asserted by Boerrhaave, has been extended into wire of the length of 500 feet; but even this has been surpassed by Dr. Wollaston; for, by surrounding the gold with silver, he has been able to extend it, so that 700 feet weighed only 1 grain, which gives a thickness of only $\frac{1}{30000}$ of an inch. The coating of silver was afterwards removed by nitric acid, which has no action on gold. Silver too is extremely ductile; so also are platinum, iron, copper, zinc, tin,

lead, nickel, palladium, and cadmium, in the order set down; and this property belongs to even some of the compound metals, especially to brass, which may be drawn into wire of great fineness. It may be observed, however, that the most ductile metals are not always the most malleable; iron, for instance, though extremely ductile, cannot be beaten into very thin laminæ.

10. Wires of the same diameter, but of different metals, are found to be capable of sustaining very different weights. This arises from their variable *tenacity*, which is estimated by gradually adding weights till the wire is broken. From the experiments of Guyton Morveau, the following are the utmost weights, which wires of 0.787 of an English line in diameter can support without breaking. (71 Ann. de Chim. 182.)

			lbs. decl. avoird. parts.
A wire of	iron	supports	549.250
————	copper	————	302.278
————	platinum	————	274.320
————	silver	————	187.137
————	gold	————	150.753
————	zinc	————	109.540
————	tin	————	34.630
————	lead	————	27.621

The tenacity of tin is greatly inferior to that of gold; and lead has still less tenacity than tin, and even than some sorts of wood.

11. Some of the malleable and ductile metals have, also, a high degree of *elasticity*. This property fits them for being applied to the mechanical purpose of springs. Steel and iron are, in this respect, superior to all other metals. Upon the properties of elasticity and hardness appear also to depend that of *fitness for exciting sound;* for whatever renders metals harder and more elastic, increases also their sonorousness. Thus bell metal is more remarkable for those properties, than either tin or copper, which are its constituents.

12. The *structure or texture* of several of the metals appears to be *crystalline.* That of iron, developed by the action of solvents, has been shown by Mr. Daniel to be fibrous. Bismuth and antimony have a lamellated texture; nickel presents a fracture between fibrous and foliated; and steel is granular. Several of the metals, when melted and cooled under favourable circumstances, form regular crystals. Thus bismuth, melted in a crucible, and suffered to cool, becomes covered with a solid crust, and when this is pierced, and the fluid beneath allowed to flow out, the cavity is found studded with beautifully regular cubic crystals. Arsenic crystallizes in regular tetrahedrons, and titanium in long filamentous prisms.

Beside the circumstances of agreement in their physical qualities, which have been enumerated, the metals resemble each other, also, in their chemical properties. Some of these resemblances it may be proper to state, for the purpose of avoiding unnecessary repetitions.

The metals, so far as we know at present, are simple or elementary bodies, and are incapable of being converted into each other. They were formerly, indeed, considered, but on very insufficient evidence, to be composed of a combustible base, peculiar to each metal, united with a general principle of inflammability, which received the name of *phlogiston*. When the metals are exposed to a strong heat, the first change which is produced in them is that they melt, or run into fusion. This effect takes place, in the different metals, at very different temperatures. Some of them may be made to boil, and are actually converted into vapour, at a heat considerably below redness; while others require a very intense heat for their fusion. By a sufficient elevation of temperature, it is probable, however, that they would all be volatilized; for platinum itself, which does not melt at a less heat than 170° of Wedgwood, has been observed to boil, when placed in the focus of a powerful burning lens. (Ann. de Chim. lxix. 92.) In some of the metals, no farther change is produced by the application of heat with the free access of air; and they return, on cooling, to their former condition. But other metals undergo a very remarkable change, accompanied, in some cases, with all the appearances of vivid combustion; in others, by no striking phenomena, and evinced only by the nature of the product. Their cohesion, lustre, malleability, tenacity, and all the properties that have been described as characteristic of them, are destroyed. Though their *absolute* weight is increased, yet they become *specifically* lighter, and they are distinguished by a new train of properties which were not observed in the metals themselves.

These changes have been very differently explained, at different periods in the history of chemical science. On the theory of phlogiston, they were accounted for by assuming that the metals, during the process of exposure to air at a high temperature, abandon their phlogiston, which, it was supposed, unites with the air, and *phlogisticates* it, thereby rendering it unfit for supporting the combustion of other inflammable bodies. The hypothesis, however, could no longer be maintained, when it was proved that the metals, so far from losing weight, become heavier by calcination.

The theory, which is now almost universally admitted, as best explaining the phenomena in question, though suggested by the hints furnished by preceding discoveries, was first reduced to a systematic and consistent form by Lavoisier. The metals, according to the views of that philosopher, are simple bodies, and undergo the changes that have already been described, in consequence of the absorption of oxygen from the air. Hence, while the metallic body becomes heavier, the air, in which the process is performed, should sustain a proportional diminution of weight. That this is the fact admits of being demonstrated, and still more readily and satisfactorily, if we employ oxygen gas instead of common air. A certain quantity of oxygen gas (or the whole indeed, under favourable circumstances) disappears; and the increase of weight in the metal is found, on examination, to be precisely equivalent to that of the gas which has been condensed. In some cases, we can even go farther, and separate the oxygen from the metal by the mere application of heat, the oxygen being recovered in the state of gas, and the metal returning to a metallic form. More satisfactory evidence than this could scarcely be required, of the nature of the change which takes place during calcination; and it may be admitted, therefore, as an established truth, that metals lose their metallic properties, in consequence of their combination with oxygen. The process has been called by Lavoisier *oxidation*, and the result of it an *oxide*. For the former term, however, Mr. Chevenix, influenced by reasons which are stated in his work on chemical nomenclature, has proposed to substitute that of *oxidizement*. In the following pages, I shall employ both these expressions indiscriminately.

The phenomena and results of the oxidizement of metals are not the same in all cases, but differ very considerably with respect to different metals.

1. Some metals are oxidized by mere exposure to atmospheric air at the ordinary temperature, and even to air which has been deprived of its hygrometric water. Arsenic, manganese, and the new metals discovered by Sir H. Davy, are perhaps the only ones which have been proved to possess this property. Potassium, indeed, has been stated by Thenard to be the only metal that is acted upon by perfectly dry oxygen gas. Others, as lead and copper, are changed by the action of the air, but extremely slowly, and not without the conjoined operation of moisture.

2. Other metals absorb oxygen from the atmosphere, but not without a considerable increase of their temperature. Iron, zinc, copper, tin, &c. when heated to redness, lose their metallic lustre, and are slowly converted into variously coloured oxides. In some instances, the process is accompanied with so abundant an extrication of light and heat, as to exhibit a vivid inflammation. This happens chiefly with some of the volatile metals. Arsenic and zinc, for example, when projected into a red-hot crucible, emit a brilliant flame. In other metals the process is unaccompanied by any remarkable phenomena, and is known to have taken place only by examining its results.

To convert the metals into oxides, there is a *degree* of heat, which is peculiar to each metal, and even to different oxides of the same metal. Mercury, for example, is oxidized, at a degree of heat which produces no change on iron; and lead at a certain temperature becomes minium, at another massicot.

3. With the exception of mercury, the metals, which have been called *perfect* (comprehending, also, gold, platinum, silver, and palladium,) are not oxidized, even by the combined operations of air and of an increased temperature. Gold, silver, and other metals of this kind, may be kept for many days in fusion, without undergoing any change. That they have an affinity, however, for oxygen, and are even capable of taking it from atmospheric air, is proved by the effect of an electrical or galvanic battery. By the former, wires formed of the perfect metals are, at the same moment, dispersed into smoke and oxidized; and, by transmitting a powerful

electric discharge, through any of the perfect metals beaten into thin leaves, the metal burns with a remarkable degree of splendour.

4. All metals that are oxidized by atmospherical air are still more readily oxidized by oxygen gas. In many cases a metal, which undergoes this change slowly and invisibly by the action of air, takes fire in oxygen gas, and exhibits a bright inflammation. For example, it has already been shown that iron wire may be entirely and vividly burned in oxygen gas.

These are the most simple cases of metallic oxidizement. In order that the changes which have been described may take place, it is necessary that there should exist a stronger affinity between oxygen and the metal than between the oxygen and light, (and perhaps the electricity) which constitute the gas; and fusion, and other modes of promoting the oxidation of metals, can only contribute to that effect by overcoming the cohesive attraction of the metallic particles. In certain cases, the phenomena become more complicated, and the metal acquires oxygen by the decomposition of some other compound, in which that element is present. Of these sources of oxygen, the most important, if not the only ones, are water, the acids, and other oxides; or compounds containing one or more of these substances.

I. Water gives up its oxygen to those metals only, which manifest a powerful affinity for that principle, and, generally speaking, to those which are most efficient in decomposing atmospherical air. The metallic bases of the alkalies and earths, with few exceptions, decompose it with a rapidity which amounts to actual inflammation; but, in general, the action of metals on water is slow at common temperatures. Iron filings, for example, when moistened with water, and confined in an inverted jar over mercury, become very gradually oxidized, and evolve hydrogen gas. But water, brought into contact with red-hot iron, is rapidly decomposed; its oxygen is transferred to the metal; and hydrogen gas is disengaged in torrents.

Water, it is observed by Gay Lussac, has the power of bringing all metals, on which it is capable of acting alone, to the same degree of oxidation as when assisted by the action of acids, sometimes to a higher degree, but never to an inferior one. Thus water by itself oxidizes tin to the *maximum*, and iron and potassium to the *medium*; but, mingled with acids, it oxidates iron and tin to the *minimum* only.

II. All those acids in which oxygen has been proved to exist, loosely combined, and which Dr. Thomson has called *supporters of combustion*, as well as the neutral salts containing them, are efficient means of oxidizing the metals. In general, the less strong the affinity of the base of any acid for oxygen, the more rapidly is the metal oxidized. Those acids, that have not been proved to contain oxygen, are remarkably inert in their action on metals; and the same inactivity belongs to other acids, in which the oxygen and base are held together by a powerful affinity. Thus concentrated sulphuric acid, at the temperature of the atmosphere, scarcely attacks any of the metals; because the oxygen and sulphur, of which it consists, forcibly attract each other. On the other hand, the nitric acid, in which there exists a large quantity of loosely combined oxygen, readily abandons a part of it, and acts on several metals with considerable energy.

Some of the acids, which, in their concentrated state, act slowly upon metals, acquire the power of oxidizing them rapidly when diluted with water. This is true of the sulphuric and muriatic acids, to either of which, when concentrated, we may apply iron or zinc, with comparatively little effect; but, on adding water, hydrogen gas is abundantly evolved, and the metal disappears. Now it is a principle, to which no exception has yet been discovered, that a metal cannot, in its perfect metallic state, unite with any acid. In order to be dissolved, it must first be brought into the state of an oxide; and, in the case which has been just now stated, no substance, capable of furnishing oxygen, is in contact with the iron except water. As an additional proof that water is, in this instance, the source of the oxygen, it has been ascertained that no portion of the acid is decomposed; but that the same quantity of acid exists in combination with oxide of iron, as was originally submitted to experiment.

By measuring, at a mean temperature and pressure, the hydrogen gas evolved in experiments of this kind, it is easy to calculate how much oxygen the metal has acquired; for every 100 cubic inches of hydrogen gas indicate the transference to the metal of 16.93 grains of oxygen. Equal weights of different metals evolve different quantities of hydrogen gas, in consequence of their combining with different quantities of oxygen, and to obtain the same volume of hydrogen gas by the solution of different metals, we must of course use different quantities of those metals. Thus 28 grains of iron, 58 of tin, 44 of antimony, and 34 of zinc, when dissolved by dilute muriatic acid, each evolve 47.2 cubic inches of hydrogen, equal to as nearly as possible 1 grain. And, as in water hydrogen is combined with eight times its weight of oxygen, 8 grains of oxygen must have united with each of the above quantities of metal. The same metal, also, in different states, may evolve different quantities of hydrogen. If, for example, the metal be impure, or already a little oxidized, it will set at liberty less hydrogen than if it were pure, or perfectly metallized. On this principle, the different proportions of real metal in several varieties of iron and steel have been investigated, the most perfectly metallized iron yielding, of course, the most hydrogen gas.

The phenomena, observed during the solution of the metal, and those attending the solution of its oxide, in the same acid, are essentially different. For the most part, a metal is dissolved with effervescence, an appearance always occasioned by the escape of gas; but the oxide seldom exhibits such a phenomenon. Iron, it has already been stated, effervesces strongly during its solution in diluted sulphuric acid; but the black oxide of that metal is taken up silently, and without any discharge of gas.

III. The metals may be oxidized by the transference of oxygen from other metallic oxides. Thus, when iron filings are distilled with the red oxide of mercury, the oxygen passes to the iron, and the mercury is *revived*, or appears in a metallic state. In a similar manner, the oxides, held in solution by acids, are decomposed by immersing, in the solution, other metals. When copper, for example, is immersed in a solution of nitrate of mercury (consisting of oxide of mercury and nitric acid), the latter metal is deprived of its oxygen by the former, and appears on the surface of the copper in a revived state. The nitrate of copper, which is thus produced, is precipitated by iron, which has a stronger affinity than copper for oxygen. A variety of similar examples might be given, in which the precipitating metal takes oxygen from that which is precipitated. In cases of this sort, it must be confessed that the comparative affinities of the acid for the oxides of the two metals may have some share in the effect, but much less than the affinities of oxygen separately considered. The precipitated metal, also, is seldom quite pure, but almost always contains a portion of the metal, which has caused the precipitation. (See Quart. Journ. xxii. 203.)

Such are the principal means of effecting the oxidation of metals. Different individuals of the class, it has already been stated, combine with different proportions of oxygen; and the same metal, it may be added, is susceptible of different degrees or stages of oxidation. Iron, for example, when united with oxygen in the proportion of 8 grains or thereabouts, to 28 grains of metal, composes a *black* oxide; and, with 12 parts of oxygen to 28 of metal, it constitutes a *red* oxide. These different oxides of the same metal have not only different colours, but each of them is characterized by a distinct train of chemical properties, and especially by different habitudes with respect to the acids. Thus the black oxide of iron readily unites with muriatic and sulphuric acids; but the red oxide less easily. The salts with base of protoxide of iron afford a white precipitate with triple prussiate of potassa; and none at all with the gallic acid, or with sulphuretted hydrogen. But the salts, in which the iron is at the maximum of oxidation, give a deep-blue compound with the triple prussiate, and a black one with the gallic acid.

It has been discussed as a question, whether the same metal is capable of uniting with oxygen, in all proportions between the maximum and minimum, or whether it does not rather combine with that principle in a few proportions only, between which there are no intermediate compounds. Berthollet, in general remarkable for the soundness and justness of his views, maintained the first opinion, and was opposed by Proust, who contended that metals unite with oxygen in two proportions only, and that the compounds, with apparently intermediate proportions, are, in fact, composed of the two extremes, variously mixed or combined. All the investigations, pursued by Proust with the view of determining this question, tended to confirm his opinion; and since his time, in a great variety of additional cases where the fact has been accurately examined, the limitation has been fully established. We may consider it, then, as a general principle, that the proportions, in which metals combine with oxygen, are few and definite; and, from the analyses which have been made of different oxides of the same metal, the metals appear to unite invariably with oxygen in such proportions, that the oxygen in the greater is a simple multiple of that in the less. It is by no means necessary, however, that the possible number of oxides of any one metal should be limited, as Proust has supposed, to two; for it is perfectly consistent with the atomic theory that there may be three, four, or even a greater number of oxides of each.

It had been long known that of different oxides of the same metal, the one, which contains a larger quantity of oxygen, is capable of saturating more acid than the one which contains less. This was ascertained by Proust, with respect to the two muriates of copper, as appears from the following statement, which still holds true, if we view the salts as in a state of solution, or as true *muriates*, and not as *chlorides*.

The green muriate consists of	100.	copper.
	24.57	oxygen.
	83.18	acid.
The white muriate of	100.	copper.
	12.28	oxygen.
	41.59	acid.

The same law appears, also, from the experiments of Sir H. Davy, to apply to the oxides of potassium and sodium. To this principle, an addition has been proposed by Gay Lussac, (Mémoires d'Arcueil, ii. 159, or 37 Phil. Mag. 200,) and supported by a variety of illustrations; *viz.*, *that the quantity of acid, which different metals require for saturation, is in direct proportion to the quantity of oxygen in their oxides.* This law, though suggested to M. Gay Lussac by his experiments on the precipitation of metals from their acid solutions, flows immediately from the atomic theory; and had, in fact, been previously employed by Mr. Dalton, as the basis of a communication made by him, in the spring of 1808, to Sir H. Davy. (Phil. Trans. 1810, p. 63, note.) A limitation, however, which does not appear to have been contemplated by Gay Lussac, is necessary to its correct enunciation; *viz.*, that the metallic oxides and those of their salts, which are made the objects of comparison, should be *similar atomic combinations.* Thus a binary compound of an acid with a *protoxide* cannot be compared with a binary compound of the same acid with a *deutoxide*; nor a *binary* combination of an acid and protoxide with a *ternary* compound of the same elements.

For example, 36 parts of protoxide of iron, or 112 parts of protoxide of lead, saturate 40 parts of sulphuric acid. Now since these oxides, and their sulphates, are alike binary compounds, the quantity of oxygen in the one should, on the above principle, be equivalent to that in the other. And this is actually the case; for 36 parts of protoxide of iron and 112 of protoxide of lead contain each 8 parts of oxygen. But if sulphate of mercury be compared with sulphate of iron, the analogy will be found no longer to exist. Of the oxide of mercury, 216 parts are required to saturate 40 of sulphuric acid. But 216 parts of this oxide contain double the quantity of oxygen contained in 36 parts of protoxide of iron. The same want of relation will be found to hold in all similar cases.

The solubility of the metallic salts in water, it has been observed by Gay Lussac, bears a proportion to the quantity of oxygen in the oxides; and, consequently, to the quantity of acid with which that oxide is combined. Salts, in which the metal is at the minimum of oxidation, are generally those which are most insoluble. This is the fact with respect to the salts of lead, silver, and mercury; for these are metals which, at the minimum of oxidizement, take very little oxygen, and consequently very little acid. A similar law is applicable to the compounds of chlorine; for corrosive sublimate, which contains the largest proportion of that element, is much more soluble than calomel, which contains the least.

There is a certain state of oxidation, peculiar to the different metals, in which they are most readily acted upon by the several acids. Iron and manganese, for example, at the maximum of oxidizement, are altogether insoluble in nitric acid; but readily dissolve in it, when combined with a smaller proportion of oxygen. Even when once brought into combination with that acid, the oxide, by attracting a further quantity of oxygen from the atmosphere, or from any other source, is separated in the state of an insoluble precipitate, which, however, does not consist of pure oxide, but of the oxide, with a certain proportion of acid. This explains the change, which is produced in solutions of iron, by keeping them exposed to air. The oxides of iron and manganese, saturated with oxygen, are soluble, however, in the less oxygenated acids; for example, in the sulphurous or nitrous, which first deprive the oxide of part of its oxygen, and then, becoming sulphuric or nitric acid, dissolve the partly de-oxidized compound.

Every acid, with a few exceptions, is capable of uniting with each individual of the classes of alkalies, earths, and metallic oxides. In these compounds, the separate qualities of the component principles are in many instances no longer apparent, and hence they have been called *neutral salts*. In every salt, then, there are present two distinct ingredients. The acid, of whatever kind it may be, has been denominated, by Lavoisier, the *salifying principle;* and the body, with which the acid is combined, whether an alkali, an earth, or an oxide of any of the common metals, the *salifiable base*, or simply *the base*. The salts, formed by an individual acid with all the different bases, may be considered as a genus or class; and may be distinguished by a generic name, expressive, in part, of their composition. This generic name is taken from that of the acid. The combination of sulphuric acid, for instance, with any base, is called a *sulphat* or *sulphate;* of phosphoric acid, a *phosphate;* and so of the rest. The name of the individual salt is derived from that of the base. Thus we have the *sulphate of potassa*, the *sulphate of soda*, &c.; and, when the name of a salt thus occurs, it is to be understood that it is a compound of one atom of each constituent. In sulphate of potassa, for instance, we have an atom of sulphuric acid united to an atom of potassa. But sulphur, phosphorus, and other bodies, it has already been observed, are susceptible of different degrees or stages of oxygenation; and afford, in these different stages, acids which are characterized by a peculiar train of properties. The compounds, also, which result from the union of two different acids, having the same combustible base, with alkalies and earths, are altogether different from each other. The salt, for example, which sulphur*ic* acid affords with potassa, is totally unlike that which results from the combination of sulphur*ous* acid with the same base. It was necessary, therefore, to distinguish the compounds of the more oxygenated from those of the less oxygenated acid; and this has been done by changing the termination from *ate* to *ite*. Thus the salts, formed with sulphurous and phosphorous acids, are called sulphites and phosphites; as sulphite of potassa, phosphite of soda, &c.

Hitherto, we have contemplated the compounds of acids with their respective bases as in the state of neutral compounds, in which neither the acid nor the base predominates. But we have several instances, in which a neutral compound is susceptible of uniting with an additional quantity of acid or of base, and of acquiring an entirely new set of properties. Potassa and tartaric acid, for example, when united in the proportions which neutralize each other, compose an extremely soluble salt, which has no action on vegetable colours; but with a double proportion of tartaric acid, a salt is formed, which requires a large quantity of water for solution, has an acid taste, and instantly reddens vegetable blue colours.

To distinguish this and other similar salts, the epithet *acidulous* was first proposed; but, for the sake of brevity, it afterwards became customary to prefix the Latin preposition *super*. Thus we have the *super*-tartrate of potassa, the super-sulphate of potassa, &c. On the contrary, when the base is predominant, the deficiency of acid was denoted by the preposition *sub*, as sub-carbonate of potassa, sub-borate of soda, &c. There are several cases, however, in which it is extremely difficult to decide, whether a salt is to be classed among neutral, or among *sub* or *super* salts. (See the remarks of Berzelius, Ann. de Chim. lxxix. 264, and lxxxii. 225.) When the *acid* of a salt is doubled, it is now most usual to prefix the Latin word *bis*, as *bisulphate* of potassa, *binoxalate* of soda; and when tripled or quadrupled, &c., *ter*, *quater*, &c., may be employed to express the proportion of acid. When the *base* is doubled, Dr. Thomson prefixes the Greek syllable *dis*. Thus *disulphate* of alumina is a compound of one atom sulphuric acid, and two atoms alumina.

There are a few instances of salts with compound bases; and in cases of this kind, it is customary to annex to the generic name those of both the bases. Thus, for example, we have the tartrate of potassa and soda, the phosphate of ammonia and magnesia, or, as it is sometimes called, ammoniaco-magnesian phosphate.

In no part of chemistry is the advantage of the new nomenclature more sensibly experienced, than in the class of neutral salts; for the number of these compounds is susceptible of being multiplied to an immense extent. If the knowledge of the name did not lead to that of the compound, scarcely any memory would be adequate to retain them. But, by changing the arbitrary titles, formerly assigned to them, for names expressive of their composition, we are furnished with a kind of artificial memory, which renders their recollection perfectly easy. Thus for the terms butter of antimony, sugar of lead, and Glauber's salt, are now substituted the more appropriate epithets of chloride of antimony, acetate of lead, and sulphate of soda.

Beside the class of acids, which are the best solvents of the metals, ALKALINE SOLUTIONS act upon metallic substances. The water which holds the alkali in solution, is decomposed; its hydrogen is disengaged, and its oxygen transferred to the metal; and the oxide, thus produced, is taken up by the alkaline liquor. The oxides ready formed are also, in several cases, dissolved by liquid alkalies. When a pure alkali is added to a metallic solution, the metal is precipitated in the state of an oxide; but the precipitate is seldom quite free from alkali, and the metallic oxide, in a few instances, instead of appearing in a separate form, is dissolved by the alkali. When alkaline carbonates are employed instead of pure alkalies, for the precipitation of metallic solutions, the oxide combines with carbonic acid, and appears in the state of a metallic carbonate.

The compounds of ammonia with metallic oxides are of more importance than those of the other alkalies, and have obtained the generic name of AMMONIURETS. They may be formed either by acting on the metals with liquid ammonia, the water of which is decomposed, and furnishes a metallic oxide, which unites with the alkali; or they may be produced, by exposing the oxides to ammoniacal gas, at the temperature of the atmosphere. At least fifteen oxides, or rather hydrated oxides, may be brought into combination with ammonia, *viz.*, oxide of zinc; deutoxide of arsenic; both the oxides of copper; oxide of silver; tritoxide and tetroxide of antimony; oxide of tellurium; protoxides of nickel, cobalt, and iron; peroxide of tin; deutoxide of mercury; and deutoxides of gold and platinum.

The ammoniurets are decomposed by a strong heat; the oxygen of the oxide uniting with the hydrogen of the alkali; and the azote of the latter being set free. In some cases, as in that of ammoniuret of gold, this decomposition is attended with a violent detonation.

The oxides, existing in metallic solutions, are decomposed by inflammable substances. Light only is sufficient for the decomposition of some of them. Hydrogen gas, charcoal, sulphur, phosphorus, and the compounds of hydrogen with the last three bodies, when brought into contact with the solutions of perfect metals at common temperatures, attract the oxygen from the metal, and occasion its precipitation in a metallic form. In this way several beautiful appearances may be produced, which will be described in treating of the individual metals.

The oxides themselves are decomposed when exposed to a strong heat in contact with hydrogen, charcoal, or phosphorus. The two first, or substances containing them, are chiefly employed for the decomposition of those oxides, which occur as natural productions.

The oxide, mixed with a portion of inflammable matter, is exposed to an intense heat; and, in order to obtain the metal in a coherent mass, and not in the small grains which would otherwise be formed, some substance is generally added, which is capable of being melted, and of allowing the metal to subside through it. Substances of this kind are called *fluxes*, and the process is termed the *revival* or *reduction* of the metal.

If only one oxide had existed of each metal, it would have been easy, by applying the general principles of chemical nomenclature, to have distinguished them by names sufficiently expressive of their composition. But, as the metals are susceptible of several stages of oxidizement, it is difficult to find terms, which shall sufficiently express the characteristic distinctions of the several oxides of the same metal.

In most instances, the denominations proposed by Dr. Thomson for the metallic oxides may be advantageously adopted. When there are several oxides of the same metal, he contrived the terms *protoxide*, *deutoxide*, *tritoxide*, &c. signifying that the metal is in its first, second, or third stage of oxidizement. Or if two oxides only of any metal are known, he suggested the appellation of *protoxide* for that at the minimum, and of *peroxide* for that at the maximum of oxidation. He has since, however, employed the term *oxide*, when used simply by itself, to denote the compound of 1 atom of metal with 1 atom of oxygen; *deutoxide*, that of 1 atom of metal with 2 of oxygen, &c.

In a similar manner, may the salts be distinguished, which result from the combination of any acid with different oxides of the same metal. Thus we have the *proto-sulphate* and *per-sulphate* of iron; and, when more than two oxides of any metal are known, it will be easy to discriminate the salts which they form, by prefixing the same abbreviated adjective as that used to denote the degree of oxidation. *Deuto-sulphate*, for example, will express a compound of sulphuric acid with a deutoxide.

The following Table exhibits, at one view, the composition of most of the metallic oxides:

Table showing the Proportions of Oxygen with which Metals combine.

Metals.	Equivalent Number of the Metal.	No. of Oxide.	Colour of Oxides.	100 of Metal take Oxygen	Authorities.	Equivalent Number of the Oxide.
Potassium	40	1	White	20.	Gay Lussac and Thenard.	48
		2	Orange	60.		64
Sodium	24	1	White	34.	Ditto.	32
		2	Orange	57.	Ditto.	36
Lithium	12	: :	White	72+	Gmelin	20
	10	: :		: :	Stromeyer.	18
Calcium	20	: :	White	39.4	Berzelius.	28

Table continued.

Metals.	Equivalent Number of the Metal.	No. of Oxide.	Colour of Oxides.	100 of Metal take Oxygen.	Authorities.	Equivalent Number of the Oxide.
Barium	70	1 2	White Grey	11.4 23.	Davy. Thenard.	78 86
Strontium	44	: :	White	18.3	Stromeyer.	52
Magnesium	12	: :	White	66.6	Thomson.	20
Glucinum	18	1	White	44.4	Ditto.	26
Yttrium	34	: :	White	25.	Ditto.	42
Aluminum	10	: :	White	80.	Ditto.	18
Zirconium	40	: :	White	20.	Ditto.	48
Silicium	8	: :	White	117.[illegible]	Berzelius.	16
Manganese	28	1 2 3	Green Brown Black	28.57 42.86 57.14	Arfwedson. Ditto. Ditto.	36 40 44
Zinc	34	1	White	24.41	Gay Lussac.	42
Iron	28	1 2	Black Red	29.5 44.25	Berzelius. Ditto.	36 40
Tin	58	1 2	Grey White	13.5 27.1	Gay Lussac. Ditto.	66 74
Cadmium	56	: :	Brownish yell.	14.352	Stromeyer.	64
Arsenic	38	1 2	White Ditto (acid)	31.57 52.63	Thomson. : :	54 62
Molybdenum	48	1 2 3	Brown Blue White (acid)	16.6 33.3 52.7	Thomson. Bucholz. Ditto.	56 64 72
Chromium	28	1 2 3	Green Brown Red (acid)	: : : : 87.72	: : : : : :	32 40 52
Tungsten	96	1 2	Black Yellow	16. 24.	: : Wöhler.	112 120
Columbium	144		White	5.5	Berzelius.	152
Antimony	44	1 2 3	Dull white White (acid) Yellow (acid)	18.2 27.3 36.4	Berzelius. Ditto. Ditto.	52 56 60
Uranium	208	1 2	Green Yellow	3.688 5.532	: : Arfwedson.	216 224

Table continued.

Metals.	Equivalent Number of the Metal.	No. of Oxide.	Colour of Oxides.	100 of Metal take Oxygen.	Authorities.	Equivalent Number of the Oxide.
Cerium	50	1	White	17.41	Hisinger.	58
		2	Fawn	26.115	Ditto.	62
Cobalt	30	1	Blue	27.3	Rothoff.	38
		2	Black	40.95	Ditto.	42
Titanium	. .	1	Blue			
		2	Red			
		3	White			
Bismuth	72	: :	Yellowish	11.275	Lagerhjelm.	80
Copper	64	1	Red	12.5	Proust and Berzelius.	72
		2	Black	25.		80
Tellurium	32?	1	Yellowish	24.8	Berzelius.	
Nickel	30		Ash grey	27.25	Rothoff.	38
		2	Black	40.88	Ditto.	46
Lead	104	1	Yellow	7.72	Berzelius.	112
		2	Red	11.08	Ditto.	116
		3	Puce	15.60	Ditto.	120
Mercury	200	1	Black	4.	Thenard.	208
		2	Red	8.	Ditto.	216
Silver	110	1	Olive	7.272	Berzelius.	118
Gold	200	1	: :	3.34	Pelletier.	208
		2	: :	10.03	Ditto.	224
Platinum	96	1	Black	8.287	Berzelius.	104?
		2	Iron grey	11.9	E. Davy.	108
		3	: :	16.38	Berzelius.	112
Palladium	56	1	: :	14.285	Ditto.	64
Rhodium	44	1	: :	18.2	Thomson.	52
		2	: :	36.4	Ditto.	60
Iridium	30	1	Blue	: :	Tennant.	
		2	Red	: :	Ditto.	

Many of the metallic oxides have an attraction for water, which they manifest by being soluble in it, or by reducing it to a solid or gelatinous form. The soluble oxides are potassa, soda, baryta, strontia, and lime; the deutoxide of arsenic, and the oxide of osmium. There are a few others, which are soluble in a very small degree only, not exceeding one thousandth of the weight of the water, *viz.*, oxide of molybdenum, deutoxide of mercury, tritoxide and tetroxide of antimony.

The compounds of oxides and water, in which the water exists in a state of true chemical union, are termed HYDRATES, or HYDRO-OXIDES, or HYDROXURES. The hydrates of potassa, soda, strontia, and baryta, retain the water which constitutes them such, at the temperature of ignition, and it can only, indeed, be expelled by bodies that have a stronger affinity for the alkali or earth. The hydrates of the remaining earths are decomposed by the heat of ignition. The hydrated oxides of the common metals are obtained by adding a solution of pure potassa, soda, or ammonia, to the solution of the oxide in sulphuric, muriatic, or nitric acid. The precipitate, washed repeatedly with water, is to be collected on a filter; and, if dried, the heat employed must be as gentle as possible; for a slight elevation of temperature is sufficient to expel the whole water, and to leave only an oxide.

The hydrated oxides are, for the most part, much more soluble in acids than the oxides. According to Berzelius, they are definite compounds, in such proportions, that the oxygen of the water is equal in weight to that of the oxide. It is, however, probable that each metallic oxide is capable of uniting with water in several definite proportions, the greater of which are simple multiples of the less.

Beside the class of compounds, which result from the union of metals with oxygen, the metals are capable, also, of entering into combination with chlorine, iodine, bromine, hydrogen, carbon, phosphorus, and sulphur. Almost all the bodies, it may be remarked, with which metals are capable of uniting in their metallic state, are, with respect to our knowledge of them, simple or elementary; and they show little if any disposition to unite with compounds, until they have themselves been rendered such by combination with oxygen, with chlorine, &c. By uniting with each other, the metals afford an interesting class of compounds called *metallic alloys*.

I. All the metals are capable of uniting with CHLORINE. The very malleable metals, such as gold, silver, &c., which can be reduced to extremely thin leaves, are best applied to chlorine gas in that state; others, as iron, zinc, copper, &c., may be introduced in the state of fine filings. For exhibiting the combustion of the latter, we may use about 40 grains of each metal to 40 cubic inches of the gas; and into the bottom of the receiver a little dry sand may be poured, to prevent it from being broken. The temperature of the gas, in order that the experiment may succeed perfectly, should not be below 70° Fahr.

The most readily oxidized metals burn with the greatest brilliancy. Metallic antimony emits a very brilliant white flame, and throws out sparks. Arsenic exhibits a fine green or blue flame, attended with sparks and a dense white smoke; bismuth, a bluish flame; zinc, a white flame and sparks; tin, a bluish white light; lead, a clear white flame; copper, a red and slowly spreading light; and iron, a bright red light.

The results of combustion in these instances are compounds of chlorine with the respective metals, which appear to be maintained by a very powerful affinity; for chlorine is capable of expelling the whole of the oxygen from any metallic oxide, and taking its place. Even those metals, that are most distinguished by their affinity for oxygen, abandon it when their oxides are heated in contact with chlorine; and oxygen gas is in that case disengaged. The same metal is capable also of uniting with different proportions of chlorine, which are definite, and, so far as has been yet ascertained, in no case exceed two proportions to one of metal. Hence it was proposed by Sir H. Davy, in fixing the nomenclature of these compounds, to designate those containing the least chlorine by the termination *ane* added to the Latin name of the metal, as *cuprane* for that of copper; and those containing most chlorine by the termination *anea*, as *cupranea*. This nomenclature, however, has not been generally adopted; but the compounds of chlorine with metals are now either called *chlorures*, or (which appears to be preferable from analogy with the similar compounds of oxygen) *chlorides*. When more than one compound exists of chlorine with any metal, that at the minimum may be called *chloride* or *proto-chloride*, and the others *deuto-chloride*, *per-chloride*, &c.

The metallic chlorides may also be formed, by exposing certain metals to muriatic acid gas at high temperatures. In this case, the muriatic acid is decomposed; its hydrogen is liberated; and its chlorine combines with the metal. Diluted muriatic acid acting on certain metals (iron for example) occasions the decomposition of water; hydrogen is evolved; and an oxide is formed, which unites with the muriatic acid and constitutes a true muriate. If the oxide of a metal be acted upon by muriatic acid, we have also a muriate formed. The muriates, in some cases, crystallize as such; but in others, in becoming solid, are at the same moment changed into chlorides. The oxides of barium, strontium, calcium, magnesium, aluminum, copper, and manganese, all form with muriatic acid crystallized muriates, containing definite proportions of water; but the oxides of potassium and sodium, when dissolved in muriatic acid, afford muriates only so long as they continue fluid, and in crystallizing become true chlorides. Mercury, silver, and lead, form chlorides only, and not muriates. When a crystallized muriate is heated, the first effect is to expel its water of crystallization, and the next is to cause the oxygen of the oxide to unite with the hydrogen of the muriatic acid, forming water which escapes. When, for instance, 124 parts of crystals of muriate of baryta are carefully heated so as to lose only 9 parts, there remain 115 of anhydrous muriate consisting of 37 muriatic acid (= 36 chlorine + 1 hydrogen) and 78 of baryta (= 70 barium + 8 oxygen); and this dry muriate being strongly heated, 1 of hydrogen unites with 8 of oxygen, to form 9 of water, and 36 of chlorine with 70 of barium, to compose 106 of chloride of barium. The chlorides may be formed also by double elective affinity; thus sulphate of mercury, exposed to heat with chloride of sodium, gives chloride of mercury and sulphate of soda; the oxygen and sulphuric acid passing from the mercury to the sodium, and the chlorine from the sodium to the mercury.

When a true metallic chloride is dissolved in water, there are two views, which may be taken, of the changes that take place; and in our choice between them we must be guided rather by probabilities, than by direct experimental evidence. Either the chloride may dissolve, as such, in the water; or a decomposition of that fluid may ensue, the chlorine seizing the hydrogen and forming muriatic acid, while the metal may compose, with the oxygen of the water, an oxide, capable of saturating the newly-formed acid. In this way, a chloride may be converted, by the action of water, into a true muriate. Against this explanation it has been alleged, that during the solution of a chloride, no one appearance takes place indicative of such an exchange of principles. The chloride, it is said, is quietly taken up, and the liquid may therefore be fairly regarded in the light of a common solution. But it must be remembered, that chemical action takes place in many instances, when it is not accompanied by any visible change, as when we mingle together solutions of certain salts, which mutually decompose each other, without precipitation or any other phenomenon. Nor in this case is the action of chlorides on water likely to be manifested by any visible transference of elements; the hydrogen of the water being exactly equivalent to convert the chlorine into muriatic acid, and its oxygen just adequate to oxidate the metal; and the two new products being, of course, precisely in the proportions necessary to mutual neutralization. Again, if we examine the solution of a chloride in water, we shall find that it actually contains muriatic acid, which is expelled by adding sulphuric acid, and there remains a distinct compound of the oxidized metal with the newly added acid. It is probable that the power of decomposing water is limited to those chlorides, of which the metallic bases have so strong an affinity for oxygen, as to decompose water at ordinary temperatures.

The compounds of chlorine with metals have been ably investigated by Dr. John Davy, and it is chiefly his results that have furnished materials for the following Table, in which the equivalent of chlorine is taken at 36. The first column contains the name of the chloride; the second the equivalent of the metal deduced from its oxide, or from some other compound; the third the proportion of chlorine; and the fourth the equivalent of the metal, derived from the lowest proportion, in which it has actually been found to unite with chlorine. In most instances, the numbers in the first and last columns will be found very nearly to coincide. When the difference is trifling, it may be imputed to errors unavoidable in analyses of this kind; but when very considerable, as in the case of arsenic, the disagreement shows the necessity of more accurate experiments either on the oxide, the chloride, or on both.

Table of the Principal Compounds of Metals with Chlorine.

Name of chloride.	Equiv. of metal.	Proportion of chlorine.	Equiv. of metal deduced from the chloride.
Chloride of Potassium - - -	40	36	40
——— Sodium - - - -	24	36	24
——— Calcium - - -	20	36	20
——— Barium - - -	70	36	70
——— Strontium - - -	44	36	44
——— Magnesium - -	12	36	12
——— Manganese - -	28	36	28
——— Zinc - - - - -	34	36	34
——— Iron, 1st - - -	28	36	28
——— 2d - - -		72	
——— Tin, 1st - - -	59	36	59
——— 2d - - -		72	
——— Arsenic - - -	38?	72	23.46
——— Antimony - - -	44	36	44.21
——— Bismuth - - -	71	36	71.05
——— Copper, 1st - -	64	36	66.05
——— 2d - -		72	
——— Lead - - - -	104	36	103.52
——— Mercury, 1st - -	200	36	204.17
——— 2d - -		72	
——— Silver - - - -	110	36	110.14
——— Gold - - - -	?	36	104.25

Chlorine is capable also of uniting with potassa, soda, and lime, and probably with other oxides. These chlorides, however, have little stability of composition, for the two first, which can only be obtained in solution, are rapidly converted into chlorate of potassa or soda, and chloride of potassium or sodium. Lime in the state of dry hydrate absorbs chlorine, and forms a compound of a more permanent nature, but still liable to be decomposed by long keeping. Of all these compounds, which are generally regarded as consisting of chlorine united with oxides, Berzelius has taken a different view. He considers them as compounds of alkalies, or of earths, with a new acid, the existence of which he deduces by analogical arguments, to which he gives the name of *chlorous acid*, and to its compounds that of *chlorites;* but of the existence of such an acid, we have at present no direct evidence. (See Ann. de Ch. et de Ph. June 1828.)

II. All the metals unite with IODINE, and form compounds which have been called *iodes*, *iodures*, or *iodides*. The last term is to be preferred, on account of the analogy of the compounds denoted by it with *oxides* and *chlorides*. The iodides of potassium, sodium, lead, and bismuth, may be obtained by bringing the vapour of iodine into contact with those oxides at a red heat. All the iodides decompose water, the hydrogen of which forms hydriodic acid with the iodine, while its oxygen is transferred to the metal, and the acid produced combines with the metallic oxide. With lime, baryta, or strontia, iodine unites at a high temperature, and in this respect differs from chlorine, which expels oxygen, and combines with the metallic base.

III. THE COMPOUNDS OF METALS WITH HYDROGEN are neither numerous nor of much importance. When water is decomposed by certain metals, at the same time that the oxygen combines with one portion, the hydrogen, which is disengaged in the state of gas, takes up another portion of metal. This is the case, in a very small degree, with iron; still more with zinc; and most remarkably with potassium, arsenic, and tellurium, all of which afford compounds with hydrogen, that have distinctly characteristic properties.

IV. THE COMBINATIONS OF METALLIC BODIES WITH SULPHUR have been divided by Vauquelin into three classes, *viz.*, 1st, the compounds of metals with sulphur, which alone are with propriety called *sulphurets*; 2dly, the compounds of sulphur with metallic oxides, termed *sulphureted oxides*; and 3dly, those of sulphureted hydrogen with metallic oxides, which may be called *hydro-sulphureted oxides*. (Ann. de Chim. xxxvii. 57.) To these may be added, 4thly, the compounds of bi-sulphureted hydrogen with metallic oxides, called *hydroguretted sulphurets*.

1. All the metals, with the exception of gold, zinc, and tin, are, in their metallic state, susceptible of direct combination with sulphur. In order to effect their union, it is sufficient that one of the bodies be in a fluid state; and as sulphur is readily fusible, a very moderate heat only is required for the purpose. Thus 28 parts of iron filings with 16 of sulphur, or 64 parts of copper filings with 16 of sulphur, when heated in a glass tube, combine, the moment the fusion of the sulphur is accomplished. The phenomena are very remarkable, consisting in a sudden and bright glow, like that of intense ignition. During combination, however dry the materials may have been, it appears from the experiments of Mr. Clayfield (Philosophical Transactions, 1808, p. 16, note,) that a quantity of elastic fluid is extricated, amounting to nine or ten times the bulk of the mixture, and consisting of sulphureted hydrogen and sulphurous acid. The former, probably, arises from the sulphur, and the latter from the metallic filings, which may have been partially oxidized by the process of washing and drying.

All the *metallic oxides* are decomposed when heated with sulphur; sulphurous acid escapes; and *metallic sulphurets* are formed. Thus when potassa and sulphur are heated together, part of the sulphur is acidified at the expense of the potassa, and the rest combines with the potassium. It does not, indeed, appear possible to form, at a high temperature, a true compound of sulphur with a metallic oxide. And even when sulphur and an oxide (potassa for instance) are boiled together with water, it is most probable that water is decomposed; that its oxygen, with 1 atom of sulphur, constitutes hypo-sulphurous acid, and that its hydrogen, with 2 atoms of sulphur, composes bi-sulphureted hydrogen, both of which products unite with the salifiable base. There result, therefore, a *hypo-sulphite*, and an *hydrogureted sulphuret*, of potassa, from which strong acids disengage sulphureted hydrogen; and also precipitate sulphur. In the act of combination as thus explained, no decomposition of the alkali is supposed to take place. Its operation is probably analogous to that of sulphuric acid in causing the decomposition of water, when the diluted acid is brought into contact with certain metals, which derive their oxygen solely from the water, and do not decompose the acid itself.

The metallic *sulphates*, also, may be employed to form sulphurets, by heating them in contact with inflammable substances. Hydrogen gas, for instance, passed over an anhydrous sulphate, ignited in a glass tube, unites with the oxygen of the base, as well as with that of the acid, and true metallic sulphurets are formed. In this way Berzelius decomposed sulphate of potassa; and Arfwedson the sulphates of manganese, zinc, cobalt, and other metals. All the metallic sulphates, too, are decomposed at a red heat by charcoal. For this purpose, when required in large quantity, they may be intimately mixed with powdered charcoal, and exposed to a strong heat in a crucible; but the resulting sulphuret is seldom pure, and is mixed with uncertain proportions of the charcoal used in excess to produce decomposition. Berthier has pointed out a more elegant mode of effecting this decomposition. (Ann. de Ch. et de Phys. xxii. 225.) He surrounds the sulphate, either reduced to powder or in mass, with charcoal, the whole being enclosed in a covered crucible, and exposes it to a white heat for two hours. In this way, the sulphate undergoes a process analogous to cementation, and loses weight equivalent to the oxygen of the base and that of the acid. With sulphates of baryta, strontia, and lime, this is correctly true; but when sulphates of potassa and soda are similarly treated, the loss is still greater, owing to the volatilization of part of the metallized product. Sulphurets, thus produced, are perfectly pure compounds of sulphur with the respective metals. They dissolve in muriatic acid with a disengagement of sulphureted hydrogen, no sulphur is precipitated, nor is any acid with that base generated. When fused with nitre in a silver crucible, a quantity of sulphate is regenerated exactly equivalent to the sulphate originally decomposed.

In these compounds, the properties of the metals cease to be apparent; for the sulphurets are brittle; have colours different from those of the metals; and, when artificially formed, are destitute of lustre. The quantity of sulphur, with which different metals are capable of uniting, varies for each metal.

The same metal, also, in some instances, combines with different quantities of sulphur, and affords compounds, characterized by a distinct train of properties. Thus the compound of 28 parts of iron with 16 of sulphur is brittle, and of a dark grey colour; has little or no lustre; and is attracted by the magnet. But 28 parts of iron with 32 of sulphur form a yellow compact compound; of sufficient hardness to strike fire with steel; and having so much lustre, as to have been often mistaken by the ignorant for gold. When different sulphurets of the same metal exist, the sulphur, in those which contain the larger proportion, is an exact simple multiple of the sulphur in those which contain the less.

The following Table exhibits the composition of several of the metallic sulphurets. In most instances I have preferred giving the results obtained by experiment, in order that it may be seen, from the numbers in the last column, how far the equivalents of the metals, deducible from the composition of the sulphurets, agree with those obtained from the analysis of the oxides. (See Table, p. 422.) In many cases, these will be found to coincide exactly. The atomic weight of lead, for instance, comes out 104, whether deduced from the oxide or the sulphuret. In other cases, there will be observed to be a difference, to a greater or less amount, between the equivalent number as inferred from the oxide and from the sulphuret; but the coincidence is still sufficiently near to allow us to consider the deviation as arising from unavoidable errors in experiment, and not from any defect in the method of induction.

Table of Sulphurets.

Name of Metal.	Authority.	Metal.	Sulphur.	Sulphur.	Metal.
Potassium	Berthier.	100	41.06	16	39.
Sodium	Do.	100	69.27	16	23.
Calcium	Do.	100	78.30	16	20.
Barium	Do.	100	24.47	16	65.
Strontium	Do.	100	36.60	16	43.
Manganese	Do.	100	56.32	16	28.
Zinc	Do.	100	50.	16	32.
Iron, 1st	Vauquelin.	100	58.75	16	27.25
—— 2d	Do.	100	117.	32	27.25
Tin, 1st	Dr. Davy.	100	27.23	16	58.9
—— 2d	Do.	100	54.5	32	58.9
Cadmium		100	28.5	16	56.
Arsenic, 1st		100	42.	16	38.
——— 2d		100	63.	24	38.
Molybdenum		100	66.5	32	48.
Chromium	Berzelius.	100	57.	16	28.
Tungsten	Do.	100	25.5	32	126.
Columbium	Rose.	100	11.	16	144.
Antimony	Berzelius.	100	37.25	16	43.
Uranium	Rose.	100	7.7	16	208.
Cobalt		100	61.5	16	26.
Titanium	Rose.	100	50.	16	32.
Bismuth	Lagerhjelm.	100	22.52	16	71.
Copper, 1st	Vauquelin.	100	25.6	16	62.5
——— 2d		100		32	64.
Nickel	Thomson.	100	57.	16	28.
Lead, 1st	Berzelius.	100	15.38	16	104.
—— 2d		100	30.8	32	104.

Table continued.

Name of Metal.	Authority.	Metal.	Sulphur.	Sulphur.	Metal.
Mercury, 1st		100	8.	16	200.
——— 2d -		100	16.	32	200.
Silver - - -	Berzelius.	100	14.9	16	107.2
Gold - - -	Do.	100	24.39	16	65.68
Platinum, 1st		100	16.7	16	96.
——— 2d -		100	33.4	32	96.
Palladium -		100	19.04	16	84.
Rhodium - -	Berzelius.	100	36.4	16	44.

Metallic sulphurets can only be partially decomposed by heat: and though this assertion appears to be contradicted by the effect of roasting these compounds, yet it is to be considered that the metals, when heated with the contact of air, absorb oxygen, and thus lose their affinity for sulphur. The sulphuret of one metal may, in many instances, be decomposed by another metal. Thus when sulphuret of mercury is distilled with a proper proportion of iron filings, the sulphur passes to the iron, and the mercury comes over in a metallic state.

When any metal, which decomposes water at ordinary temperatures, is made to combine atom to atom with sulphur, the metal still disunites the elements of that fluid. An atom of metal takes an atom of oxygen from an atom of water, and the disengaged atom of hydrogen forms, with an atom of sulphur, an atom of sulphureted hydrogen. When a diluted acid is employed, the same changes take place; and also the newly formed oxide unites with its equivalent of acid. All this is well illustrated by the action of sulphuret of potassium on water.

Concentrated sulphuric acid, with the assistance of heat, acts upon metallic sulphurets, and is converted into sulphurous acid, which, being volatile, escapes. (Berthollet, Annales de Chimie, xxv. 256.) Metals which, in their separate state, were dissolved by dilute sulphuric acid, continue sensible to its action, after being combined with sulphur. When dilute sulphuric acid, however, acts on such compounds, instead of hydrogen gas simply, we obtain sulphureted hydrogen. It is chiefly the compounds with the minimum of sulphur, that produce this effect; for the *per-sulphurets*, or those containing the maximum proportion of sulphur, resist the action of dilute sulphuric acid; or, if soluble, their solution is accompanied with a separation of sulphur.

Concentrated muriatic acid has no effect on sulphurets; but the diluted acid acts like the diluted sulphuric. Nitric acid is decomposed by the metallic sulphurets; nitrous gas is disengaged; and sulphur is precipitated. (Vauquelin, loc. cit. 65.) In this case, though all nitric acid contains water, yet sulphureted hydrogen is not formed, because the acid yields its oxygen more easily than the water.

Caustic alkalies decompose all the proto-sulphurets; and so also do the alkaline carbonates, but only at a red heat and when in contact with charcoal. The phenomena and results of this mutual action have been well studied by Berthier, and explained in a memoir in the Ann. de Ch. et de Ph. xxxiii. 154.

Sulphurets, composed of metals which powerfully attract oxygen, and the oxides of which have moreover an affinity for sulphuric acid, absorb oxygen from the atmosphere, and pass to the state of *sulphates*. In this way most of the sulphate of iron is formed, which occurs in commerce. But if the metal has either a strong affinity for sulphur, or a weak one for oxygen, then the conversion into a sulphate does not happen, as in the sulphurets of copper, antimony, and mercury. (Berthollet, loc. cit. 256.) That sulphuret of iron, which contains a full proportion of sulphur, resists, also, the conjoined action of air and moisture.

2. In general, the metals have a stronger affinity than their oxides for sulphur; but there are a few cases, in which certain metals are said to be incapable of combining with sulphur, till they are brought into the state of oxides. These are chiefly zinc, mercury, and manganese, the compounds of which with sulphur, if they can be shown to exist at all, may be called *sulphureted oxides*.* Other metals, also, are capable of affording similar compounds: but in general their affinity for sulphur diminishes, in proportion to the quantity of oxygen which they hold in combination.

Sulphureted oxides act on acids, somewhat differently from the mere sulphurets. If the metal be only oxidized at its minimum, they yield sulphureted hydrogen with diluted muriatic and sulphuric acids, and nitrous gas with nitric acid. But in their perfectly oxidized state, the oxides dissolve without effervescence, and the sulphur remains unaltered.

3. Sulphureted hydrogen enters into combination with a few of the metals, with mercury and silver for example; but it unites, in general, more readily and permanently with their oxides. From such compounds, the sulphureted hydrogen is detached in a gaseous state by some concentrated acids, which seize the metallic oxide. Most of the sulphureted oxides, also, undergo, in process of time, spontaneous decomposition, in consequence of the union of the hydrogen and oxygen which they contain, and which, by combination, form water. When this happens, the oxide is partly reduced, and the sulphur unites with the deoxidized metal. Hence the same sulphureted oxide varies in composition, according to the period which has elapsed since its preparation.

When we precipitate a metallic solution by sulphureted hydrogen either alone, or by its compounds with alkalies, we obtain in the first case, a metallic sulphuret; in the second, a hydro-sulphuret.

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* Vauquelin asserts, (Ann. de Chim. et de Phys. v. 6,) that the oxides of manganese and iron are decomposed by sulphur, and that true metallic sulphurets are formed; and Berzelius is decidedly of opinion that sulphur cannot unite with an oxidized body. But Arfwedson conceives that he has established the existence of a sulphureted oxide of manganese, the elements of which are in atomic proportion. (An. de Ch. &c. xxvii. 179.)

In the first case, the hydrogen of the sulphureted hydrogen takes all the oxygen of the oxide; and the sulphur forms a true sulphuret with the reduced metal. In the second case, the sulphureted hydrogen unites directly with the oxide, without decomposing it, and its proportion is such that the hydrogen is sufficient to saturate all the oxygen of the oxide. The quantity of hydrogen, then, which is destroyed, or may be destroyed, depends on the state of oxidizement of the metal, and so also does the quantity of sulphur. Now since metals are susceptible of oxidation in only a few determinate degrees, it follows that by precipitations of this kind, we may obtain metallic sulphurets with fixed proportions, which may be easily calculated from the known quantity of oxygen in the oxide, and the known composition of sulphureted hydrogen. (Gay Lussac, Mémoires d'Arcueil, ii. 175.)

4. Hydrogureted sulphurets of metals and their oxides may be obtained by precipitating metallic solutions with the hydrogureted sulphurets of alkalies. In sulphureted oxides, the metal, sulphur, hydrogen, and oxygen, exist in atomic proportions, so that the oxygen is precisely sufficient to change the sulphur into acid, the metal into protoxide, and the hydrogen into water. But if the affinity of the metal for oxygen be inferior to that of hydrogen, the oxide is then reduced, and water and a sulphuret are generated. Thus the alkalies, the earths, and the protoxides of zinc and manganese, afford, with sulphureted hydrogen, saline combinations; but the oxides of lead and copper are decomposed by it. (Berzelius, 79 Ann. Ch. 129.)

It had been generally supposed that metals, which have a great affinity for oxygen, and which decompose water (as manganese, iron, zinc, uranium, nickel, cobalt, &c.) are not precipitated from their solutions by sulphureted hydrogen, except with the concurrence of double affinities. Gay Lussac, however, has shown (80 Ann. de Chim. 205) that the compounds of these metals with the weaker acids (as the acetic, tartaric, and oxalic) are decomposed by sulphureted hydrogen, and produce hydro-sulphurets of the respective metals. When a still weaker solvent of the metal is employed, the decomposition is more easily effected. Thus the ammoniurets of iron, nickel, &c., are entirely decomposed by that gas; and this furnishes an excellent process for obtaining pure hydro-sulphurets; for the alkaline hydro-sulphurets, commonly employed for this purpose, are almost always contaminated with sulphur in excess. Those metals, which are not precipitable by sulphureted hydrogen, become so, when acetate of potassa is added to their solutions.

V. Several metals have an affinity for phosphorus, and form a class of compounds called METALLIC PHOSPHURETS. The best method of effecting this combination is to expose the metals to heat, in contact with phosphoric acid and charcoal. The charcoal deprives the phosphorus of oxygen; and the deoxygenized phosphorus unites with the metal. Metals, however, that have a strong affinity for oxygen, decompose the phosphoric acid, and unite with its base, without the intervention of charcoal. The metallic phosphurets have not hitherto been applied to any useful purpose; and it is sufficient, therefore, to refer to the description of them by Pelletier, in the first and thirteenth volumes of the Annales de Chimie, and to a Memoir by Rose, in the Ann. de Ch. et de Ph. Feb. and Aug. 1827.

VI. There is one compound body for which the metals, in their metallic state, have a strong affinity, *viz.*, CYANOGEN. With this compound of carbon and nitrogen they constitute *cyanurets* or *cyanides*, which have the property of decomposing water, the cyanogen forming with its hydrogen *hydro-cyanic acid*, while the metallic base with its oxygen constitutes an oxide. This is precisely analogous to what takes place with chlorides. For metallic oxides, cyanogen appears to have very little affinity, and it forms with them unstable compounds.

VII. The compounds of metals with carbon are called CARBURETS. That of iron, and carbon, the properties of which vary according to the proportion of the two ingredients, is the only one of importance. It will be described in its proper place.

VIII. The metals are, for the most part, capable of uniting with each other. For this purpose, they require to be brought into a state of fusion; and, even when melted, considerable care is necessary to form a permanent compound. If one metal is considerably heavier than the other, it is apt to sink to the bottom of the fluid mass. Nothing can show this in a more striking manner, than a fact which has been stated by Mr. Hatchett. He found that when gold, which has been melted with a proportion of copper or other metals, is cast into bars, the moulds for which are placed vertically, the lower part of the bar contains more gold in proportion than the upper part.

There are a few of the metals that do not unite by being fused together. This is the case with lead and iron; but even in such cases we are scarcely, perhaps, entitled to deny all affinity; for some of the metals, which were formerly thought incapable of combination, have been made to combine by circuitous processes. This is the fact with respect to iron and mercury. (Aikin, in Philosophical Magazine.)

In the new nomenclature, the word ALLOY is retained as a general term for all combinations of metals with each other; and the specific name is derived from that of the metal, which prevails in the compound. Thus in the *alloy of gold with silver*, the gold is to be understood as being in greatest proportion; in the *alloy of silver with gold*, the silver is the principal ingredient. The compounds of mercury with other metals, at a very early period of chemistry, were called AMALGAMS, and as the name does not lead to any erroneous notions, it may still be retained to denote this sort of alloy.

The metals in general have been supposed capable of uniting with each other in unlimited proportions; but a careful examination of those alloys, which are characterized by peculiar properties, and adapted to specific uses, has shown that such compounds are definite, and fall within the general laws of the atomic system.

This proposition has been ably maintained by Berzelius, as well as by Dalton. Potassium, the former observes, gives with mercury two crystallized compounds, one of which contains twice as much potassium as the other. The *arbor Dianæ* is a definite compound of silver and mercury. When zinc and copper are distilled together, a certain quantity of zinc comes over, but the rest cannot be raised by heat. From a fused mixture of antimony, iron, and copper with much tin, metallic crystals separate on cooling, containing fixed proportions of the component metals. Whenever, indeed, the new compound has an opportunity of separating from the fused mass, it appears to be formed in established proportions.

By combination with each other, the metals undergo a considerable change of properties, and acquire new ones, not observable in the separate metals.

1. The *specific gravity* of an alloy is seldom the mean of those of its component parts. Thus an alloy of silver with copper or tin, or one of silver or gold with lead, has a greater than the mean specific gravity. An alloy, also, of silver with mercury, though the former metal is specifically lighter than the latter, possesses so much acquired density as to sink in quicksilver. In other cases, on the contrary, the specific gravity of the compound falls short of the mean of that of its components, or there appears to be a degree of dilatation, as in the alloys of gold with copper, iron, or tin; and of tin with lead. In the last case, for example, 116 parts of tin and 104 of lead should give a compound of sp. gr. 9.321, but the real sp. gr. of the alloy is only 8.817, showing that an expansion has attended the union of those two metals. (Thomson's First Princ. i. 39.)

2. The *ductility* and *malleability* of metals is generally changed by being alloyed together; and, for the most part, these qualities are impaired. Even two metals, which separately are both malleable and ductile, may be rendered brittle by combination. This is very remarkably the case with an alloy of gold and lead, the latter of which, even in the trivial proportion of half a grain to an ounce of gold, renders the alloy quite destitute of tenacity; and an alloy of platinum, copper, and zinc, though eminently ductile and malleable, is rendered brittle by a quantity of iron not exceeding half a grain in four ounces of the alloy. (Quart. Journ. iii. 119.) In such cases, it has been supposed that a true chemical union does not take place, and that the newly added metal is merely mechanically interposed between the particles of the other, the cohesion of which it thus impairs. This explanation, however, can scarcely be admitted as satisfactory; and, among other arguments in proof of the existence of chemical union, it may be remarked, that gold is rendered brittle by being kept in fusion in the vicinity of melted tin, the vapour of which it seems capable of attracting.

3. The *hardness* of metals is varied by combination. Gold, by combination with a small quantity of copper, and silver by a minute proportion of the same metal, acquire such an increase of hardness, that these additions are always made to gold or silver which is to be exposed to wear. By a small addition of gold, iron is said to

gain so much hardness, as to be even superior to steel for the fabrication of cutting instruments.

4. *Change of colour* is a common effect of the combination of metals with each other. Arsenic, for example, which resembles steel, and copper, which has a red colour, afford by their union a compound which has nearly the whiteness of silver.

5. The *fusibility* of compound metals is different from what might have been inferred from that of their components. Platinum, for example, is rendered easily fusible by arsenic, and a compound of lead, tin, and bismuth, melts at a temperature below that of boiling water, though the most fusible of the three (tin) requires for its fusion a much higher degree of heat than 212°. This is the principle of *solders*.

6. Metals have their *volatility* increased, by being combined with other metals which are more volatile than themselves. Gold, separately, requires an intense heat for its volatilization; but when an amalgam of gold with mercury is distilled, a quantity of gold passes over with the quicksilver.

7. By chemical union with each other, the metals have their *tendency to combine with oxygen* considerably increased, partly in consequence of the diminution of their cohesion, but in some cases, in consequence of their forming a galvanic combination. Lead, when amalgamated with mercury, is oxidized by merely shaking the compound with water. Lead and tin, melted together, acquire such an increase of affinity for oxygen, that, at the moment of combination, they actually inflame. By the oxidation of either of the ingredients of these alloys, the compound is destroyed. The oxide of lead, for example, separates from mercury in the form of a black powder. Hence, also, a pellicle of oxide is generally observed on the surface of melted solders, and is renewed as soon as it is removed.

8. The solubility of metals in acids is modified by their combination with each other. When gold is alloyed with a small proportion of silver, the latter metal is protected from the action of the nitric acid; and, in order to render it soluble in that acid, it is necessary to raise its proportion to one-fourth the weight of the alloy, which constitutes the process of *quartation*. In a similar manner, in order to render tin capable of being entirely dissolved out of an alloy of that metal with antimony, it is necessary that it should constitute 20 parts out of 21 of the alloy; in which case the tin is wholly dissolved by boiling with muriatic acid, and the antimony is left untouched. (Chaudet, Ann. de Chim. et de Phys. iii. 382.)

From a comparison of the resemblances among metals, both as to physical and chemical properties, several divisions of them have been contrived into smaller classes. I know, however, of no arrangement, the principle of which is not liable to strong objections, and which is not contradicted by so many exceptions, as to set aside the rule. The circumstance, on which subdivisions of the metals have been generally founded, is their relation to oxygen, consisting in the comparative degrees of their attraction for that basis. But it is not easy to measure the degrees of these attractions; nor is it clear whether we are to determine them by facility of union, or by difficulty of decomposition. If we take the property of decomposing water, at common temperatures, as the character of an order, we shall find that the metallic bases of some of the earths (glucinum and yttrium, for example) do not possess that property; and yet the close analogy of their oxides with other earths renders it improper to place their metallic bases apart from those which act powerfully in disuniting the elements of water. Again, combustibility in air, at ordinary temperatures, cannot be taken as a ground of classification; for this varies greatly with the mechanical state of the metal. This is proved by the interesting remarks of Magnus, showing that metals, not otherwise spontaneously combustible, become so when revived in a spongy or finely divided form. (Ann. de Chim. et de Ph., xxx. 103.) Under these circumstances, I shall omit all minuter divisions, and adopt the old arrangement of them into two classes:

CLASS I. METALS, THAT AFFORD OXIDES, WHICH CANNOT BE REDUCED TO A METALLIC STATE WITHOUT THE ADDITION OF COMBUSTIBLE MATTER.

CLASS II. METALS, THE OXIDES OF WHICH MAY BE DECOMPOSED BY HEAT ONLY.

The first is the most comprehensive class, and includes, indeed, all the metals, with the exception of mercury, silver, gold, platinum, palladium, rhodium, iridium, osmium, and nickel. These nine metals compose the second class.

◆

CLASS I.

METALS, WHOSE OXIDES ARE NOT REDUCIBLE BY HEAT, WITHOUT THE ADDITION OF COMBUSTIBLE MATTER.

SECTION I.

Of Potassium.

This metal was discovered by Sir H. Davy in 1807, and was obtained from a compound of potassium and oxygen, which will be described in this section under the name of potassa. To this discovery he was led by a train of inductive reasoning, which is not surpassed by any investigation in the history of the physical sciences.

From the facts which have been stated in a former section, respecting the powers of electrical decomposition, it appeared to be a natural inference, that the same powers, if applied in a state of the highest possible intensity, might disunite the elements of some bodies, which had resisted all other instruments of analysis. If potassa, for example, were an oxide, composed of oxygen united to an inflammable base, it seemed probable that, when subjected to the action of opposite electricities, the oxygen would be attracted by the positive pole and repelled by the negative. At the same time, the reverse process might be expected to take place with respect to the combustible base, the appearance of which might be looked for at the negative pole.

In his first experiments, suggested by these views, Sir H. Davy failed to effect the decomposition of potassa, owing to his employing the alkali in a state of aqueous solution, and to the consequent expenditure of the electrical energy in the mere decomposition of water. In his next trials, the alkali was liquefied by heat in a platinum dish, the outer surface of which, immediately under the alkali, was connected with the zinc or positive end of a battery consisting of 100 pairs of plates, each six inches square. In this state, the potassa was touched with a platinum wire proceeding from the copper or negative end of the battery; when instantly a most intense light was exhibited at the negative wire, and a column of flame arose from the point of contact, evidently owing to the development of combustible matter. The results of the experiment could not, however, be collected, but were consumed and dispersed immediately on being formed.

The chief difficulty in subjecting potassa to electrical action is, that in a perfectly dry state it is a complete non-conductor of electricity. When rendered, however, in the least degree moist by breathing on it, it readily undergoes fusion and decomposition by the application of strong electrical powers. For this purpose, a piece of potassa, weighing from 60 to 70 grains, may be placed on a small insulated plate of platinum, and may be connected, in the way already described, with the opposite end of a powerful electrical battery, containing not less than 100 pairs of six-inch plates. On establishing the connexion, the potassa will fuse, at both places where it is in contact with the platinum. A violent effervescence will be seen at the upper surface, arising, as Sir H. Davy ascertained, from the escape of oxygen gas. At the lower or negative surface, no gas will be liberated; but small bubbles will appear, having a high metallic lustre, and being precisely similar in visible characters to quicksilver. Some of these globules burn with an explosion and bright flame; while others are merely tarnished, and are protected from farther change by a white film, which forms on their surface.*

This production of metallic globules is entirely independent of the action of the atmosphere; for Sir H. Davy found that they may be produced *in vacuo*.

To preserve this new substance, it is necessary to immerse it immediately in pure naphtha, a fluid which will be described in a subsequent part of the work; for if exposed to the atmosphere, it is rapidly converted back again into the state of potassa. To prevent its oxidation still more effectually, Mr. Pepys proposed to produce it under naphtha, and contrived an ingenious apparatus for this purpose, which is described in the 31st volume of the Philosophical Magazine, page 241.

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* For the repetition of this experiment, very useful practical directions may be found in a paper by Mr. Singer.—Nicholson's Journal, xxiv. 174.

Nothing, then, can be more satisfactory than the evidence furnished by these experiments, of the nature of one of the fixed alkalies. By the powerful agency of opposite electricities, it is resolved into oxygen and a peculiar base. This base, like other combustible bodies, is repelled by positively electrified surfaces, and attracted by negative ones; and hence its own natural state of electricity must necessarily be positive. Again, by uniting with oxygen, it is once more changed into alkali, either slowly at ordinary temperatures, or with heat and light at high temperatures. We have the evidence, therefore, both of analysis and synthesis, that potassa is a compound of oxygen with a peculiar inflammable basis.

In assigning to this newly discovered substance a fit place among the objects of chemistry, Sir H. Davy was induced to class it among the metals, because it agrees with them in opacity, lustre, malleability, conducting powers as to heat and electricity, and in its qualities of chemical combination. The only property, which can be urged against this arrangement, is its extreme levity, which even exceeds that of water. But, when we compare the differences which exist among the metals themselves, this will scarcely be considered as a valid objection. Tellurium, for example, which no chemist hesitates to consider as a metal, is only about six times heavier than the base of potassa, while it is four times lighter than platinum; thus forming a sort of link between the old metals and the bases of the alkalies.

In giving names, therefore, to the alkaline bases, Sir H. Davy has adopted that termination, which, by common consent, has been applied to other newly discovered metals, and which, though originally Latin, is now naturalized in our language. The base of potassa he has called POTASSIUM, and the base of soda SODIUM; and these names have met with universal acceptation among chemical philosophers.

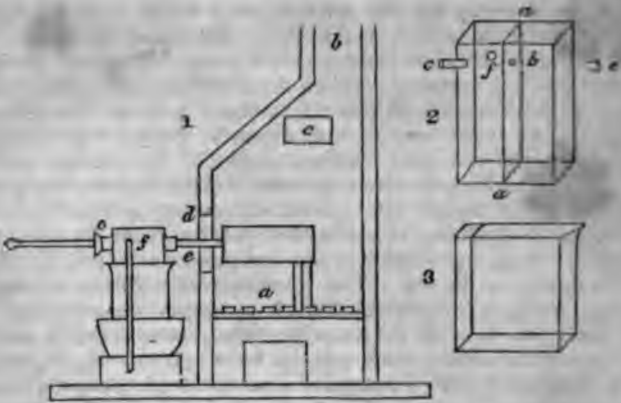
Process for preparing Potassium.

It is not by electrical means only, that the decomposition of potassa has been effected. Soon after Sir H. Davy's discoveries were known at Paris, Messrs. Gay Lussac and Thenard succeeded in their attempts to decompose both the fixed alkalies, without the aid of a Voltaic apparatus, by bringing the alkalies into contact with intensely heated iron, which, at this temperature, attracts oxygen more strongly than the alkaline base retains it. (Mémoires d'Arcueil, ii. 299.) The apparatus, used by them for obtaining potassium, has a general resemblance to that which is employed for decomposing water by means of iron. In the former editions of this work, it was described and represented by a plate; but it has been since superseded by other contrivances of greater simplicity, which do not require so intense a degree of heat. M. Brunner (Quart. Journ.

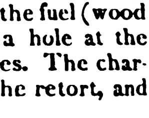
xv. 279,) employs, for the purpose of a retort, a spheroidal iron bottle, about half an inch in thickness, and capable of holding about a pint of water, into the shorter end of which a gun-barrel, bent into this form (/') is screwed. When the retort is charged and luted, it is placed in a furnace, so that the longer leg of the bent gun-barrel may pass out at the bottom or in front, in a direction nearly perpendicular, the bent part itself remaining in the furnace, and being wound round with iron wire to protect it from the fire. The receiver is a cylindrical copper vessel, with an opening at the top to admit the end of the gun-barrel, and a tube passing from the side, to convey away the gas produced in the operation. It is placed, when in use, in water or in ice. The decomposition of the potassa, M. Brunner finds, is greatly facilitated by employing charcoal along with the iron. Into the retort, after being cleaned, dried, and heated, 4 ounces of solid caustic potassa were introduced, in small portions, alternately with 6 ounces of iron turnings, broken in a mortar and mixed with 1 ounce of pulverized charcoal. The whole was stirred together, and covered with 2 ounces of iron turnings; and the retort being luted, and the barrel adapted, the fire was lighted and gradually raised. In half an hour, the green vapours of potassium appeared in a glass tube, which had been attached to the end of the barrel for the purpose of watching the process. The receiver containing naphtha was now applied, so that the end of the barrel dipped into the fluid. An immense production of gas took place, which frequently took fire spontaneously, and burned with a violet flame and white fumes. In twenty-five minutes from the application of the receiver, the gas diminished in quantity, and soon entirely ceased coming over. The receiver was then separated, and found to contain 150 grains of potassium. Eight ounces of fused sub-carbonate of potassa, 6 ounces of iron filings, and 2 ounces of charcoal, similarly treated, gave 140 grains of potassium. Crude tartar (impure bi-tartrate of potassa) was found also to yield potassium in the proportion of 150 grains from 12 ounces of tartar. The substitution of the two last-mentioned salts makes the process much more economical; and the employment of charcoal renders so much lower a heat necessary than for the common method, that the same retort served for as many as thirty operations.

The preparation of potassium has been farther improved by M. Wöhler, of Berlin. The apparatus, which he employs, is described in the Annales de Mines, xii. 175, and in the Quart. Journ. xxii. 206, from the latter of which the annexed cut, and much of the description, are copied. I am enabled, also, by the kindness of a friend (Dr. Fleming, of Manchester), who had an opportunity of seeing the process performed at Berlin, to supply the omission, in the account alluded to, of a few details which may tend to facilitate the operation.

The furnace, No. 1, is about four feet high, and nearly two feet square. The bars of the grate stand a little above the level of the floor, and rest upon a bearer, by the removal of which they may be made to fall down together, and thus the fire may be removed at any required moment. The draught of air is from a room below.



About the middle of the front of the furnace at *d* is a square hole, capable of containing two bricks, and within the body of the furnace, a little below the above-mentioned opening, are two bars of iron, placed horizontally, and dividing the space within the furnace equally. Two other bars cross these, and are tied to them by iron wire, in such a manner as to make a firmer seat for the retort than by a single brick as shown in the cut. The retort is an iron bottle of the kind used for containing quicksilver. A square piece of stone is hollowed to receive the tube (a piece of gun-barrel, about a foot long), screwed into the retort; and a brick is placed over the stone, so as to fill up the square opening mentioned above. The whole is then covered with luting, and the iron bottle, with its contents, is placed in the furnace, as represented in the figure, in which *a* is the grate; *b*, the flue; *d*, the square opening through which the apparatus is introduced, and which is afterwards closed and luted over; *c*, the opening for introducing fuel; but, in the instance witnessed by Dr. Fleming, the fuel (wood charcoal) was supplied more conveniently through a hole at the top, (see fig. 62,) which had a lid furnished with hinges. The charcoal fire was at least four inches above the top of the retort, and the body of fire perhaps eight inches below it.



The receiver (figs. 2 and 3) is the invention of M. Berzelius. It is a foot high, 6 inches long, about 4 inches wide, and is best when made of strong sheet copper. It is composed of two pieces; No. 2 is of such a size as to pass into No. 3 with some degree of friction. It may be either right-angled or elliptical. The part No. 2 is divided into two equal parts by a diaphragm *a a*, pierced by a small hole *b*, on the same line with the tubulures *c* and *e*; and on one of its larger faces is a third tubulure *f*, by which the gases are allowed to escape. If the receiver be oval, the diaphragm may be placed in its greater diameter. Naphtha is put into the receiver, No. 3, till about half full, and the receiver is then placed in a wooden trough containing ice-water, kept cold by fresh additions of ice. Lastly, the tubulure *e* is adapted to the end of the gun-barrel, and the joint made tight by a little lute, if necessary. The gas generated in the retort enters the receiver by the tubulure *e*, and, as it is obliged to pass by the very small aperture at *b*, it deposits the greater part of its potassium before it passes out by the tube *f*. It also deposits a cetain portion on the other side of the diaphragm; and, finally, to collect the last portion which it may contain, a large glass tube is connected with the aperture at *f*, and its extremity generally is plunged into naphtha. The gas frequently takes fire, and must be extinguished, as well as the naphtha, if the flame should extend to it.

The operation is known to be going on well by the regularity of the current of gas flowing through the tube *f*, the cessation of which indicates an obstruction of the gun-barrel by a black substance accumulating in it, probably a compound of potassium, carbon, and potassa. The tubulure *c* is then to be opened, it being generally closed by a cork; and by passing a ramrod, flattened at one end, through the apertures *c*, *b*, and *e*, the tube is to be well cleared out. This, though quite necessary, must yet be done carefully; for a sudden rush of gas through the openings *c*, *f*, might cause serious accidents. M. Gmelin places the diaphragm of his receiver in the direction of its length, and is thus enabled to introduce the blade of a sword, by which he can clear the tube better than with a rod.

The tube may easily be cleared two or three times, but at length it becomes so clogged up, that the process must be suspended, by first withdrawing the bars of the grate, and letting the fuel fall. Remove the retort, unscrew the tube, fill it with naphtha, and detach the substance which it contains; reunite it, replace the retort in the fire, and proceed to distil the remainder of its contents. In this way the operation may be repeated three or four times, and, rising from 4 to 6 pounds of crude tartar, about an ounce of potassium will be obtained each time. By distilling the black matter detached from the iron tube, the half of its weight of potassium may be obtained.

The potassium, prepared with charcoal, always contains carbonaceous matter, and requires to be purified by distilling it in divided portions from a glass retort, heated to redness in a sand-bath, the neck being very much inclined, and plunged into a vessel full of naphtha.

In the iron tube, after the operation, a grey substance is found, of such hardness that it can only be detached by a chisel. From this M. Gmelin extracted an acicular orange-coloured salt, composed of potassa united with a peculiar acid, to which he has given the name of *croconic acid*. (Quart. Journ. xxii. 208.)

Properties of Potassium.

Potassium, at 70° Fahr., exists in small globules, which possess the metallic lustre, opacity, and general appearance of mercury; so that when a globule of mercury is placed near one of potassium, the eye can discover no difference between them. At this temperature, however, the metal is only imperfectly fluid; but, when gradually heated, it becomes more and more fluid; and at 150° Fahr. its fluidity is so perfect, that several globules may easily be made to run into one.

By reducing its temperature, potassium becomes, at 50° Fahr. a soft and malleable solid, which has the lustre of polished silver. It is soft enough, indeed, to be moulded by the fingers like wax, but should be covered by a film of naphtha to prevent it from taking fire. At about the freezing point of water, it becomes hard and brittle, and exhibits, when broken, a crystallized texture, which, under the microscope, seems composed of beautiful facets of a perfect whiteness and high metallic splendour.

To be converted into vapour, potassium requires a temperature approaching that of ignition; and, when the experiment is conducted under proper circumstances, it is found unaltered after distillation.

Potassium is a perfect conductor both of electricity and of heat.

Its specific gravity at 60° Fahr., making some allowance for unavoidable errors in the experiment, is, according to Gay Lussac and Thenard, 0.865. Bucholz states it at 0.876, and Sir H. Davy, in general terms, as between .8 and .9, water being considered as 1.

At the temperature of the atmosphere, potassium acts on oxygen gas, even when the gas is deprived of its hygrometrical moisture; but, to produce its full effect, it is necessary that it should be in thin flattened pieces, as it soon becomes covered with a coating of oxide, which protects the mass beneath from further action. If heated nearly to redness, or to its point of vaporization, it burns with a brilliant white flame and a very intense heat.

Potassium appears to be susceptible of different degrees or stages of oxidizement. By heating it to a point, below what is necessary for its inflammation, either in common air or oxygen gas; or (which is still better), by confining it for some days in an empty phial loosely corked, a substance is formed of a bluish grey colour, softer than wax, and readily fusible. This substance takes fire in oxygen gas, or even common air, at about 70° Fahr., and acts on water, giving out hydrogen, but in less quantity than is extricated by potassium. It is now, however, generally considered not as a distinct oxide, but a mixture of that which is next to be described with metallic potassium.

The true *protoxide of potassium* is best obtained by the action of potassium on water. This is attended with some striking phenomena. When potassium is thrown upon water exposed to the atmosphere, or, when it is brought into contact with a drop of water, it decomposes the water with great violence; an instantaneous explosion is produced with a vehement flame; and a solution of pure potassa is the result. The hydrogen gas, which is disengaged, appears to dissolve a portion of potassium; for on escaping into the air, it forms a white ring of smoke, gradually enlarging as it ascends, like that produced by phosphureted hydrogen gas.

When water is made to act on the base of potassa, atmospheric air being excluded, there is much heat and noise, but no luminous appearance; and the gas evolved is pure hydrogen. Each grain of potassium, by acting on water, detaches about 1.06 cubic inch of hydrogen gas.

If a globule of the base of potassa be placed on ice, it instantly burns with a bright flame, and a deep hole is made in the ice, filled with a fluid which is found to be a solution of potassa.

The production of alkali, by the action of water on potassium, is most satisfactorily shown by dropping a globule of the metal upon moistened paper, which has been tinged with turmeric. At the moment when the globule comes into contact with the paper, it burns, and moves rapidly, as if in search of moisture, leaving behind it a deep reddish brown trace, and acting upon the paper exactly like dry caustic potassa. So strong, indeed, is the affinity of potassium for oxygen, that it discovers and decomposes the small quantities of water contained in alcohol and ether, even when carefully purified, and disengages from both these fluids hydrogen gas.

On naphtha, colourless and recently distilled, potassium has very little power of action; but in naphtha, which has been exposed to the air, it soon oxidizes, and alkali is formed. This unites with the naphtha into a brown soap, that collects round the globules.

Potassa.—Hydrate of Potassa.—Peroxide of Potassium.

It was important to determine the proportions, in which potassium and oxygen unite when potassa is regenerated. This Sir H. Davy investigated by two different processes. The one consisted in ascertaining how much oxygen gas is absorbed by a known weight of potassium; the other, how much hydrogen is disengaged from water by that metal; and, dividing the evolved hydrogen gas by 2, he learned the quantity of oxygen which had been abstracted from the water. By the united evidence of these methods of investigation, he determined that 75 parts of potassium, to become potassa, absorb 15 parts by weight of oxygen, a result which coincides very nearly with that of Gay Lussac and Thenard, who found that 100 of potassium, by acting on water, combine with 19.945, or, in whole numbers, with 20 of oxygen. Hence potassa is constituted of

Potassium - -	83.34	- - - - - - 40	= 1 atom.
Oxygen - - -	16.66	- - - - - - 8	= 1 atom.
	100.	Atomic weight 48	

This, however, applies to potassa only when perfectly pure, and free from water. In this state it is white, extremely caustic, turns the syrup of violets green; is fusible a little above a red heat; and is deliquescent, and therefore very soluble in water. When heated in oxygen gas, it absorbs a farther proportion of oxygen, and from the state of protoxide passes to that of the orange-coloured *peroxide.*

The precise nature of the orange-coloured compound was first explained, and its properties examined, by Gay Lussac and Thenard. It is fusible at a lower heat than hydrate of potassa, and crystallizes in laminæ by cooling. When thrown into water, oxygen gas is evolved, and it passes to the state of protoxide. The same change occurs by exposing it on a platinum tray, coated with fused chloride of potassium, to a heat considerably above that at which it was produced. It is constituted of 1 atom of potassium = 40, + 3 atoms of oxgen = 24, and its representative number is 64. Potassium, then, presents the anomaly of a metal combining with 1 atom and with 3 atoms, but not with the intermediate proportion of 2 atoms of oxygen.

Potassa, as generally obtained by chemical operations, is not the pure protoxide, but is intimately united with a certain proportion of water. The credit of this discovery is due to Darcet, who has established his claim to it very satisfactorily. The solid hydrate of potassa appears to be constituted of an atom of protoxide = 48, + an atom of water = 9, and its equivalent number is therefore 57.

Preparation of Potassa.

Hydrate of potassa may be prepared as follows: Dissolve any quantity of American or Dantzic pearlash in three or four times its weight of boiling water; or, if the alkali be required particularly pure, substitute carbonate of potassa, which has been prepared by burning a mixture of one part of pure nitre with two of super-tartrate of potassa. Add this solution to an equal weight of fresh burned quicklime, first slacked to a fine powder, and then diffused through water sufficient to render the mixture quite fluid. Boil these ingredients in an iron kettle, and continue stirring for half an hour. Then separate the liquid alkali, either by subsidence, or by straining through calico, and boil it to dryness in a silver dish. Put the dry mass into a bottle, and pour upon it as much pure alcohol, as is necessary to dissolve all that is soluble in that fluid. Then decant the alcoholic solution of potassa, and distil off the alcohol, in an alembic of pure silver fitted with a glass head. (See pl. i. fig. 2.) Pour the alkali, when in fusion, upon a silver dish, and, as soon as cold, break it into pieces, and preserve it in well-stopped vials. If the whole of the alcohol be not thus separated, the potassa will shoot, on cooling, into regular crystals, which are probably an *alcohate* of potassa. For common purposes, it is sufficient to boil down the watery solution, and to fuse the residue; and thus prepared, especially when procured from nitre and tartar, it is sufficiently pure for affording potassium. In all accurate experiments of research, however, it is necessary to employ hydrate of potassa which has been purified by alcohol.

From the electro-chemical researches of Sir H. Davy, it appears that potassa is not completely deprived of carbonic acid, by any process hitherto employed for its preparation. It is probable that the method suggested by Darcet, of removing the last portions of carbonic acid from the alkaline solution, after the action of quicklime, by adding solution of baryta, would be found effectual. The potassa is apt, during concentration in the alembic, to act upon the alcohol, and disengage a portion of charcoal; and also to dissolve a minute quantity of silver.

The solution of hydrate of potassa has, when concentrated, an intensely acrid taste, and destroys the texture of animal and vegetable substances. It changes the colour of the violet to green; neutralizes acids without effervescing with them; dissolves resins; and converts fixed oils and fat into soap. Hence it is powerfully detergent. When evaporated to dryness, it may be fused by raising the heat, and becomes solid on cooling. If a portion, thus solidified, be dissolved in water, oxygen gas is sometimes given out. (Graham, in Brewster's Journ. No. 13, p. 186.)

It is often of importance to know the quantity of real potassa contained in solutions of different specific gravities. For this purpose the following Table has been constructed by Mr. Dalton. The first of the liquid compounds is that containing 1 atom of potassa + 2 atoms of water.

Table of the Quantity of Real Potassa in Watery Solutions of different Specific Gravities.

Atoms of potassa water.	Potassa per cent. by weight.	Potassa per cent. by measure.	Specific Gravity.	Congealing point.	Boiling point.
1 + 0	100.	240	2.4	unknown.	unknown.
1 + 1	84.	185	2.2	1000°	red heat.
1 + 2	72.4	145	2.0	500°	600°
1 + 3	63.6	119	1.88	340°	420°
1 + 4	56.8	101	1.78	220°	360°
1 + 5	51.2	86	1.68	150°	320°
1 + 6	46.7	75	1.60	100°	290°
1 + 7	42.9	65	1.52	70°	276°
1 + 8	39.6	58	1.47	50°	265°
1 + 9	36.8	53	1.44	40°	255°
1 + 10	34.4	49	1.42		246°
	32.4	45	1.39		240°
	29.4	40	1.36		234°
	26.3	35	1.33		229°
	23.4	30	1.28		224°
	19.5	25	1.23		220°
	16.2	20	1.19		218°
	13.	15	1.15		215°
	9.5	10	1.11		214°
	4.7	5	1.06		213°

Chloride of Potassium.

When potassium is heated in chlorine gas, it burns much more vividly than in oxygen; each grain absorbs 1.1 cubic inches of the gas, and a neutral compound is formed, which is a true chloride of potassium. The same compound is formed by heating potassium in muriatic acid gas, for in this case the gas is decomposed into chlorine, which unites with the metal, and hydrogen, which is liberated in a gaseous state. It may also be procured by dissolving either hydrate or carbonate of potassa in muriatic acid, and evaporating the solution to perfect dryness. In the first instance, muriate of potassa is formed, which, by the subsequent application of heat, is converted into chloride of potassium; the hydrogen of the muriatic acid uniting with the oxygen of the potassa, and forming water, which is volatilized.

According to Sir H. Davy, chloride of potassium is composed of 75 potassium + 67 chlorine, proportions which nearly agree with those stated by Gay Lussac, *viz.*, 111.31 potassium + 100 chlorine. Hence it is constituted of 1 atom of potassium, = 40, + 1 atom of chlorine = 36, and its equivalent number is 76. One hundred grains, according to Berzelius, when dissolved in water, and decomposed by nitrate of silver, yield 192.4 of fused chloride of silver, formerly called *luna cornea.* (See vol. ii. Chap. on Silver.)

When chloride of potassium is dissolved in water, a double elective affinity is supposed to operate; water is decomposed; its hydrogen, uniting with the chlorine, composes muriatic acid; and the oxygen of the water, being transferred to the potassium, constitutes potassa. The acid and alkali together form muriate of potassa. By evaporating the solution, crystals are again obtained of chloride of potassium. These crystals are cubical, have a bitter disagreeable taste; undergo little change when exposed to the air, and when suddenly heated to redness decrepitate, with a very trifling loss of weight, arising from the escape of a little water, held mechanically between the plates of the crystals. They are soluble in three times their weight of water at 60° Fahr., and in a rather less proportion of boiling water.

Considered as muriate of potassa (in which state this salt most probably exists when in watery solution), it may be regarded as constituted of an atom of muriatic acid 37, and an atom of potassa 48, and its representative number is 85. But there are some chemists who regard it, even when dissolved in water, as still constituting a true *chloride.*

Iodide of Potassium.

This compound may be formed, by heating potassium in a tube of green glass with an excess of iodine. At the moment of combination light appears, which, being seen through the vapour of iodine, has a purple hue.

Iodide of potassium enters into fusion, and is volatilized at a heat below redness. It dissolves readily in water, which, during solution, it decomposes, forming a neutral hydriodate of potassa, and this salt, being exposed to a pretty strong heat in close vessels, gives out water, and is re-converted into iodide of potassium. It is constituted of 1 atom of potassium = 40, + 1 atom of iodine = 125, and its representative number is 165.

Potassium with Simple Acidifiable Bodies.

With hydrogen potassium forms two compounds, the one gaseous, the other solid. The first results from the action of potassium on water, the hydrogen of which, while in a nascent state, dissolves a portion of the metal. It may also, as appears from Sir H. Davy's experiments, be formed directly by heating the metal in hydrogen gas. A large portion of potassium is thus dissolved; but the greater part precipitates on cooling.

The gaseous compound is spontaneously inflammable in the atmosphere; burns with a very brilliant light, which is purple at the edges; and throws off dense vapours of potassa. It loses its inflammability by keeping; is heavier than hydrogen gas; and is very dilatable by electricity. Besides the gas, which is spontaneously combustible, there is also, according to Sementini, another compound of potassium and hydrogen, which is not possessed of this property, and probably contains a less proportion of the combustible metal.

Gay Lussac and Thenard have succeeded, also, in forming a solid compound of potassium and hydrogen. (Recherches, i. 176.) The process consists in heating the metal in hydrogen gas; and the only difficulty is to regulate the heat, for a high temperature decomposes the solid compound. The flame of a spirit-lamp, applied to potassium, in a retort filled with hydrogen gas, occasions an absorption of the gas, and the formation of a solid *hydruret of potassium.*

The colour of this hydruret is grey; it is destitute of metallic lustre; and is infusible. It is not inflammable, either in air or in oxygen gas at common temperatures, but burns vividly at a high one. When strongly heated in a close vessel, it is totally decomposed; all the hydrogen it contains is liberated in the state of gas; and the potassium remains. When brought into contact with heated mercury, hydrogen gas is evolved, and an amalgam of potassium and mercury is produced.

Nitrogen gas has not, at any temperature, any action on potassium.

Potassium with sulphur.—When sulphate of potassa is decomposed by hydrogen gas or by charcoal at a red heat, the residue is a compound of sulphur and potassium. It is difficult to obtain it perfectly pure, for it acts both on glass and on platinum. When prepared in glass, it has a pale cinnabar colour, and a crystalline fracture; fuses at a heat below redness; and then becomes dark and opaque. It attracts moisture from the air, and dissolves into a yellowish fluid, which, when diluted with water, becomes colourless. This appears to be a sulphuret of the first degree of sulphuration.

When potassium is fused with sulphur, in a vessel filled with the vapour of naphtha, a rapid combination ensues, accompanied with heat and light, and a disengagement of sulphureted hydrogen. The result is a grey *sulphuret of potassium,* not unlike artificial sulphuret of iron. Its formation and properties have been investigated by Vauquelin. (Ann. de Ch. et de Phys. vi. 22.)

By fusing sub-carbonate of potassa with double its weight of sulphur, out of the contact of air, a sulphuret of potassium is formed, in which 100 of the metal are united with 207.7 of sulphur, which is equivalent to 10 atoms. Varying the proportions, Berzelius, to whom we owe these facts, obtained sulphurets which he regards as compounds of 1 atom of potassium with 2, 4, 6, 7, 8, 9, and 10 atoms of sulphur. (Ann. of Phil. N. S. iv. 284.)

Potassium, in combination with sulphur, and not in a free state, appears to be the active principle of the spontaneously combustible compound called *pyrophorus*. Of these there are several species, which will be described in speaking of the pyrophorus of Homberg, in the Section on Alum.

The *phosphuret of potassium* may be formed by fusing potassium with phosphorus under naphtha. It requires for its fusion a stronger heat than either of its constituents. It is of the colour of lead; and, when spread out, has a lustre similar to polished lead. By exposure to the air, or by rapid combustion, it forms phosphate of potassa. Besides this, there is, also, a chocolate-coloured compound of potassium and phosphorus; so that it is probable these two bodies unite in different proportions, the lead-coloured compound consisting of 2 atoms of metal + 1 of phosphorus; and the chocolate of 1 atom of metal + 1 of phosphorus.

Compounds of Potassium with Metals.

With mercury, potassium gives some extraordinary and beautiful results. The combination, which is very rapid, is effected by merely bringing the two metals into contact at the temperature of the atmosphere. The amalgam, in which the potassium is in least proportion, seems to consist of about 1 part in weight of basis and 70 of mercury. It is very soft and malleable; but, by increasing the proportion of potassium, we augment, in a proportional degree, the solidity and brittleness of the compound.

The compound of mercury and potassium may be obtained by an easy and simple process, first pointed out by Berzelius. Mercury, to the depth of a line, is put into a glass capsule, two inches in diameter, with a flat bottom. On this a solution of pure potassa is poured; an iron wire connects the mercury with the negative pole of a galvanic arrangement, which needs not contain more than 20 pairs of plates; and a spiral platinum wire, from the positive pole, is immersed in the solution, and kept about one-tenth of an inch from the surface of the mercury. In six hours, the effect is observable, and in twenty-four is very distinct; for, in that time, more than 1200 grains of mercury will be rendered solid by combination with potassium. Unfortunately, this combination cannot be so decomposed as to obtain the potassium in a separate state.

In this state of division, potassium appears to have its affinity for oxygen considerably increased. By exposure to the air for a few minutes, potassa is formed, which deliquiates, and the mercury is left pure and unaltered. When a globule is thrown into water, it produces a rapid decomposition and a hissing noise; potassa is regenerated; pure hydrogen disengaged; and the mercury remains free.

The fluid amalgam of potassium and mercury dissolves all the metals; and, in this state of union, mercury even acquires the power of acting on platinum.

Potassium unites, also, with gold, silver, and copper; and, when the compounds are thrown into water, this fluid is decomposed, potassa is formed, and the metals are separated unaltered. When the reduction of an ore has been accomplished by the use of fluxes containing potassa, M. Vauquelin has shown that the revived metal contains a greater or less proportion of potassium, which modifies its properties. By exposure to the air, or by the action of water, this impurity may be removed. (Ann. de Chim. et de Phys. vii. 32.)

Potassium reduces all the metallic oxides when heated with them, even of those metals which most powerfully attract oxygen, such as oxides of iron. In consequence of this property, it decomposes and corrodes flint and green glass by a very gentle heat; potassa is generated with the oxygen taken from the metal, which dissolves the glass, and exposes a new surface. At a red heat even the purest glass, formed merely of potassa and silica, is acted upon. The alkali in the glass seems to give up a part of its oxygen to the potassium, and an oxide of potassium results, with a less proportion of oxygen than is necessary to constitute potassa. The silica, also, it is probable, is partly deoxidized.

Salts of Potassa.

Chloride of Potassa.

There can be little doubt of the existence of such a salt as chloride of potassa, although it is one of very unstable composition, and constantly tending to be converted into chloride of potassium and chlorate of potassa. This re-action will be explained in speaking of the latter salt, and of the analogous properties of chloride of lime. (See Morin, Ann. de Ch. et de Phys. xxxvii. 154.)

Chlorate (Hyper-oxy-muriate) of Potassa.

This salt was discovered by Berthollet. It may be formed either by the direct mixture of liquid chloric acid with solution of potassa or carbonate of potassa; or by passing chlorine gas, as it proceeds from the mixture of chloride of sodium, sulphuric acid, and manganese, through a watery solution of caustic potassa, the exact specific gravity of which does not appear to be of importance, but which should not be very strong. For this purpose Woulfe's apparatus may be employed, using only one three-necked bottle in addition to the balloon. The tube, which is immersed in the alkaline solution, should be at least half an inch in diameter, to prevent its being choked up by any crystals that may form. The solution, when saturated with the gas, and heated, is converted into chlorate of potassa and chloride of potassium, in the proportions, according to Morin, of 1 of the former to 18 of the latter; but Chevenix states the chlorate produced to be nearly as 1 to 5. The solution, being evaporated, yields crystals, of which only the first products are to be reserved for use; for the subsequent crystals consist of chloride of potassium only.

When obtained by the last-mentioned process, the changes which take place admit of being explained as follows: Part of the chlorine may be employed in decomposing the water of the alkaline solution, forming, with its hydrogen, muriatic acid, while another portion of chlorine may unite with the oxygen thus set at liberty; or the change may consist in the decomposition of potassa, the oxygen of one portion of which may be transferred to another portion, while the chlorine is partly expended in decomposing water and forming muriate of potassa, and partly in forming a triple compound of chlorine, oxygen, and per-oxide of potassium. In this view, chlorate of potassa is constituted of 1 atom of potassium, weighing 40, 1 atom of chlorine = 36, and 6 atoms of oxygen = 48; and its equivalent number is the sum of these, *viz.*, 124.

Even by the advocates of the simple nature of chlorine, two different views have been taken of this class of salts. By Gay Lussac, the chlorates are considered as compounds of chloric acid with alkaline and earthy bases; by Sir H. Davy, they are regarded as triple compounds of 1 atom of chlorine, 1 atom of metallic base, and 6 atoms of oxygen. But chloric acid being, as is *deducible* from the experiments of Gay Lussac, compounded of 5 atoms of oxygen with 1 atom of chlorine; there is no difference as to the facts, whatever there may be as to their explanation. This will appear from the following comparative statement:

According to Davy,

Chlorates consist of	1 atom of metallic base 1 atom of chlorine 6 atoms of oxygen.

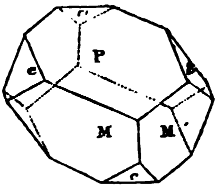
According to Gay Lussac,

Chlorates are composed of	1 atom of base, consisting of	1 atom metal 1 atom oxygen.
	1 atom of chloric acid	5 atoms oxygen. 1 atom chlorine.

It will easily be perceived, on examining these statements, that the same proportions of elements are assigned by both philosophers to the chlorates, and that the only difference is one of opinion, as to the manner in which those elements are arranged.

The chlorate of potassa has the following qualities:

(*a*) It has the shape of shining hexahedral laminæ, or rhomboidal plates. The primary form is an oblique rhombic prism. The cleavage parallel to the planes M and M′ is easy, and the cleavage



planes are brilliant, but the crystals are generally too thin to obtain a cleavage plane parallel to P. The measurements are as follows:

P on M, or M' -	105° 30'
M on M' - - -	104 0
P on c' - - - -	106 45 dull
P on e, or e' - -	129 45

The crystals of this salt are described also by Mr. Levy. (Quart. Journ. xv. 286.)

(*b*) One part of the salt requires 17 of cold water for solution, but 5 parts of hot water take up 2 of the salt.

(*c*) It is not decomposed by exposure to the direct rays of the sun, either in a crystallized or dissolved state.

(*d*) When chlorate of potassa is submitted to distillation in a coated glass retort, it first fuses, and, on a farther increase of temperature, yields oxygen gas of great purity; for the whole product contains not more than 2 or 3 per cent. of nitrogen gas. (See page 188.) Berzelius, from 100 grains, obtained 39.15 grains = 112 or 114 cubic inches of oxygen gas. (Ann. de Chim. et de Phys. v. 175.) And Gay Lussac found that 100 grains give 38.88 grains of oxygen, and 61.12 of chloride of potassium, equivalent to 28.93 chlorine and 32.19 potassium. The residue of this distillation, Vauquelin asserts, is sensibly alkaline; from whence it should appear that the capacity of saturation is less in chlorine than in chloric acid. (Ann. de Chim. et de Phys. xcv. 101.)

(*e*) The chlorate of potassa has no power of discharging vegetable colours; but the addition of a little sulphuric acid, by setting chlorine at liberty, develops this property.

(*f*) The salt is decomposed by the stronger acids, as the sulphuric and nitric. This may be proved by dropping a few grains of the salt into a little concentrated sulphuric acid in a wine-glass. A strong smell will arise, and, if larger quantities of the materials be heated in a retort, a violent explosion sometimes ensues. The experiment should, therefore, be performed with caution. When this mixture is made at the bottom of a deep vessel, the vessel is filled with euchlorine gas, which inflames sulphuric ether, alcohol, or oil of turpentine, when poured into it; and also camphor, resin, tallow, elastic gum, &c. (Davy.)—By the action of sulphuric acid, regulated as already described, (page 198), peculiar gaseous compounds result.

Muriatic acid, as has already been stated, disengages chlorine from chlorate of potassa, and the addition of a few grains of the salt to an ounce measure of the acid, imparts to it the property of discharging vegetable colours.

(*g*) Chlorate of potassa exerts powerful effects on inflammable bodies.

1. Rub 2 grains into powder in a mortar, and add 1 grain of sulphur. Mix them very accurately, by gentle triture, and then, having collected the mixture to one part of the mortar, press the pestle down upon it suddenly and forcibly. A loud detonation will ensue. —Or, if the mixed ingredients be wrapped in some strong paper,

and then struck with a hammer, a still louder report will be produced.

2. Mix 5 grains of the salt with half the quantity of powdered charcoal in a similar manner. On triturating the mixture strongly, it will inflame, especially with the addition of a grain or two of sulphur, but not with much noise.

3. Mix a small quantity of sugar with half its weight of the salt, and on the mixture pour a little strong sulphuric acid.* A sudden and vehement inflammation will be produced. This experiment, as well as the following, requires caution.

4. To 1 grain of the powdered salt in a mortar add about half a grain of phosphorus. The phosphorus will detonate, on the gentlest triture, with a very loud report. The hand should be covered with a glove in making this experiment, and care should be taken that the phosphorus, in an inflamed state, does not fly into the eyes.—Phosphorus may also be inflamed under the surface of water by means of this salt. Put into a wine-glass, 1 part of phosphorus with 2 of the chlorate; fill it nearly with water, and pour in, by means of a glass tube, reaching to the bottom, three or four parts of sulphuric acid. The phosphorus takes fire, and burns vividly under the water. This experiment, too, requires caution, lest the inflamed phosphorus should be thrown into the eyes. (Davy). Oil may also be thus inflamed on the surface of water, the experiment being made with the omission of the phosphorus, and the substitution of a little olive or linseed oil.

5. Chlorate of potassa may be substituted for nitre in the preparation of gunpowder, but the mixture of the ingredients requires extreme circumspection, on account of their liability to explode by trituration. It may be proper also to state, that this salt should not be kept mixed with sulphur in considerable quantity, such mixtures having been known to detonate spontaneously.

Per-chlorate of Potassa.

This salt may be formed by mixing one part of powdered chlorate of potassa with three of sulphuric acid, and cautiously exposing the mixture to heat till it turns white, when we obtain a mixture of bi-sulphate and per-chlorate of potassa. The former being much more soluble than the latter in cold water, their separation may be effected by solution and crystallization.

Per-chlorate of potassa does not change vegetable colours. It requires more than fifty times its weight of water at 60° for solution; and crystallizes by evaporation in lengthened octohedrons. Distilled at 280° Fahr., with an equal weight of sulphuric acid, it yields per-chloric acid. When heated *per se* to 412°, oxygen is evolved, and chloride of potassium remains. It is constituted of 1 atom of per-chloric acid = 86, + 1 atom of potassa = 45, and its representative number is therefore 131.

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* A mixture of this kind is the basis of the matches now generally used for the purpose of procuring instantaneous light. The bottle, into which they are dipped, contains concentrated sulphuric acid, which is prevented from escaping by a quantity of finely spun glass, or of the fibres of amianthus.

Iodate and Hydriodate of Potassa.

Both these salts are formed by agitating iodine with a solution of potassa; water is decomposed, and gives origin to a very soluble hydriodate, and a difficultly soluble iodate. The latter may be purified by being washed first with a little water, and afterwards with alcohol sp. gr. .820, which removes the hydriodate. The iodate remains in small white and granular crystals.

When projected on red-hot coals, iodate of potassa acts like saltpetre; 100 parts heated in a retort give 22.59 oxygen gas, and 77.41 iodide of potassium. It requires for solution 13½ parts of water at 60° Fahr. It is constituted of 22.246 potassa and 77.754 iodic acid.

Hydriodate of potassa is deliquescent, and consequently very soluble. It is constituted of 100 hydriodic acid + 37.426 potassa. By crystallization, or simple desiccation, it is changed into iodide of potassium, which is easily fused and volatilized without change at a red heat.

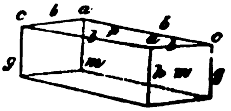
Nitrate of Potassa.

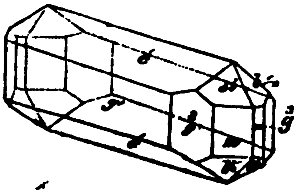
A direct synthetic proof of the composition of this salt may be obtained by saturating nitric acid with potassa, either pure or in a carbonated state. The solution, on evaporation, yields crystals of nitrate of potassa.

For the purpose of experiment, the nitrate of potassa, which may be purchased in the shops under the name of nitre or saltpetre, and which is an abundant product of nature, may be employed on account of its greater cheapness. The nitre, which is met with as an article of commerce, is brought to this country chiefly from the East Indies. When it arrives, it is a very impure salt, containing, besides other substances, a considerable proportion of muriate of soda. In this state it is called rough nitre. For the purposes of chemistry, it requires to be purified by solution in water and recrystallization; and it then obtains the name of refined nitre, or refined saltpetre.

This salt has the following properties:

(*a*) Its crystals are thus represented and described by Mr. Levy. (Quart. Journ. xv. 284.)





Incidences.

m on m	109° 50′
$b^{\frac{1}{2}}$	135° 36′
g^3	160° 42′
e^1 on g^1	120° 25′

Primitive form.—A right rhombic prism, the incidence of the two lateral planes of which is 109° 50′, and the ratio between one side of the base and the height nearly that of 1 to 0.48.

Cleavage.—Parallel to all the faces of the primitive, and also to a plane passing through the two short diagonals of the bases.

All the best analyses of nitrate of potassa concur in showing that it is anhydrous, and composed of

1 atom of nitric acid	52.94	54	= 1 atom.
1 atom of potassa	47.06	48	= 1 atom.
	100.	102	

Its equivalent number is, therefore, 102; and as the atom of nitric acid contains 5 atoms of oxygen and 1 of nitrogen, and the atom of potassa 1 atom of oxygen and 1 of potassium, we have in each atom of nitrate of potassa 6 atoms of oxygen.

(*b*) For solution, it requires seven times its weight of water at 60° Fahr.; and boiling water takes up its own weight. This is the degree of solubility assigned by Bergman; but La Grange asserts, that, at the ordinary temperature, nitrate of potassa requires only three or four times its weight of water for solution; and half its weight of boiling water. (Manuel, 1st edit. i. 243.) With the addition of common salt, it becomes considerably more soluble.

(*c*) By the application of a moderate heat it fuses, and, being cast in moulds, forms what is called *sal prunelle*. After fusion, Sir H. Davy found that it still yielded water, when distilled with boracic acid; but this, as water does not appear to be essential to it, had probably been held between the plates of the crystals, or absorbed from the atmosphere, in the act of reducing it to powder.

(*d*) If a red heat be applied, nitrate of potassa is decomposed in consequence of the destruction of its acid. By distilling it in an earthen retort, or in a gun-barrel, oxygen gas may be obtained in great abundance, 1 pound of nitre yielding about 12,000 cubic inches, of sufficient purity for common experiments, but not for purposes of accuracy. The last portions of the gaseous product were found by Mr. R. Phillips to be principally azotic gas. On pouring water into the retort, he observed oxygen gas to be abundantly evolved. This shows that peroxide of potassium must have been produced and then decomposed into oxygen and potassa. (Ann. of Phil. April 1827.)

(*e*) Nitrate of potassa, that has been made red-hot, seems to contain an acid less highly oxygenated than the nitric acid, and having a weaker affinity for alkalies. For if acetic acid be poured on nitre that has been thus treated, the nitrous acid is expelled in red fumes.

whereas common nitre is not at all affected by acetic acid. In this state it may be considered as a *nitrite* of potassa. (Thomson's First Princ. of Chem. i. 107.)

(*f*) Nitrate of potassa is rapidly decomposed by charcoal at a high temperature. This may be shown, by mixing two parts of powdered nitre with one of powdered charcoal, and setting fire to the mixture in an iron vessel under a chimney. The gaseous products of this combustion, which may be collected by a proper apparatus, are carbonic acid and nitrogen gas. Part of the carbonic acid also remains attached to the residuary alkali, and may be obtained from it by adding a stronger acid. This residue was termed, by the old chemists, *clyssus* of nitre.

(*g*) Nitrate of potassa is also decomposed by sulphur, and with different results, according to the temperature and proportions employed.

1. Mix equal weights of powdered nitre and sulphur, and throw the mixture, by a little at a time, into a red-hot crucible. The sulphur will unite with the oxygen of the nitric acid, and form sulphuric acid; which, combining with the potassa, will afford sulphate of potassa. The production of the latter salt will be proved by dissolving the mass remaining in the crucible, and crystallizing it, when a salt will be obtained exhibiting the characters of the sulphate of potassa.

2. Mix a portion of sulphur with one-sixth or one-eighth its weight of nitrate of potassa; put the mixture into a tin cup, and raise it, by a proper stand (fig. 25), a few inches above the surface of water, contained in a flat shallow dish. Set fire to the mixture, and cover it with a bell-shaped receiver. In this case, also, sulphuric acid will be formed; but it will not combine, as before, with the alkali of the nitre, which alkali is present in sufficient quantity to absorb only a part of the acid produced. The greater part of the acid will be condensed on the inner surface of the glass bell, and by the water, which will thus become intensely acid. The operation may be repeated three or four times, using the same portion of water. When the water is partly expelled, by evaporation in a glass dish, concentrated sulphuric acid remains.

(*h*) A mixture of three parts of powdered nitre, two of carbonate of potassa, or common salt of tartar, and one part of sulphur, all accurately mixed together, forms the *fulminating powder*, which explodes with a loud noise, when laid on an iron plate heated below redness.

(*i*) A mixture of five parts of powdered nitre, one part of sulphur, and one of powdered charcoal, composes *gunpowder*. The materials are first very finely powdered separately, then mixed up together, and beaten with a wooden pestle, a sufficient quantity of water being added to prevent an explosion. The mixture is afterwards granulated, by passing through sieves, and dried very cautiously.*

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* On the preparation of gunpowder, and the theory of its detonation, consult Nicholson's Journal, xxiii. 277.

Carbonate of Potassa.

Carbonate (sometimes called *sub-carbonate*).—The simplest mode of showing the absorption of carbonic acid by potassa, is the following: Fill a common phial with carbonic acid gas over water, and, when full, stop it by applying the thumb. Then invert the bottle in a solution of pure potassa, contained in a cup, and rather exceeding in quantity what is sufficient to fill the bottle. The solution will rise into the bottle, and, if the gas be pure, will fill it entirely. Pour out the alkaline liquor, fill the bottle with water, and again displace it by the gas. Proceed as before, and repeat the process several times. It will be found, that the solution will condense many times its bulk of the gas; whereas water combines only with its own volume.

This experiment may be made, in a much more striking manner, over mercury, by passing into a jar, about three-fourths filled with this gas, a comparatively small volume of a solution of pure potassa, which will condense the whole of a large quantity of the gas. If dry hydrate of potassa be substituted in this experiment, no change will ensue; which proves that solution is essential to the action of alkalies on this gas. A solution of potassa, which has condensed all the carbonic acid it is capable of absorbing, when evaporated to dryness, affords *sub-carbonate*, or, more properly, *carbonate of potassa*.

The composition of this salt is differently stated by chemical writers, *viz.*,

	Acid.	Base.
According to Dalton, 100 grains consist of -	31.10 - -	68.9
Dulong - - - - - - - - -	30.70 - -	69.30
Dr. Wollaston - - - - - - -	31.71 - -	68.29

The proportions of 31.71 to 68.29 agree very nearly with the notion, that the carbonate of potassa is constituted of an atom of carbonic acid, weighing 22, and an atom of potassa, weighing 48; and that the weight of its atom is 70. The affinity of carbonic acid for potassa, though apparently feeble, is, in reality, very strong; since it has the power of expelling from potassa the whole of the water, which that alkali contains in the state of a hydrate; for carbonate of potassa contains no combined water, after being long exposed to a red heat. As commonly met with in the shops, under the name of *salt of tartar*, it contains, however, from 12 to 16 per cent. of water. In this state it is probably a proto-hydrate, with a slight excess of water, which it is difficult to expel, so as to leave a compound with exactly atomic proportions.

The solution of carbonate of potassa will be found to have a much milder taste than the pure alkali, and not to destroy the texture of woollen cloth; but it still turns to green the blue infusion of vegetables. In the pure alkaline solution, no remarkable change ensued on mixing it with diluted sulphuric acid: but if that, or almost any other acid, be now added, a violent effervescence will ensue, arising from the escape of carbonic acid gas.

For experimental purposes, carbonate of potassa may be obtained from crystals of tartar (bi-tartrate of potassa), calcined in a crucible; then lixiviated with water; and evaporated to dryness. By this treatment, the salt yields about one-third its weight of dry carbonate. Or the tartar may be mixed with about an eighth of purified nitrate of potassa, and wrapped up in paper in the form of cones, which may be placed on an iron dish, and set on fire. The residuary mass is to be lixiviated, and evaporated as before directed. Or, lastly, purified nitrate of potassa may be mixed with a fourth of its weight of powdered charcoal, and projected into a red-hot crucible, the contents of which are to be poured, when in fusion, into an iron dish. The carbonate, thus obtained, amounts to rather less than one-half the nitre which has been employed. Even when thus prepared, it is apt to contain impurities, consisting chiefly of a minute proportion of sulphate and muriate of potassa, with a little silica, from which it is extremely difficult entirely to free it. That which is procured from burnt tartar may be easily made to crystallize, in which state it contains 20.60 per cent. of water; or the crystals consist of

1 atom carbonic acid - - -	22
1 atom potassa - - - - -	48
2 atoms water - - - - -	18
	88

The *potash* and *pearlash of commerce* are carbonates of potassa, of different degrees of purity. The quantity of carbonic acid, contained in these alkalies, may be learned by a very simple experiment. Put 1 or 200 grains of the alkali into a Florence flask, and add a few ounce-measures of water. Take also a phial filled with dilute sulphuric acid, and place this, as well as the flask, in one scale. Balance the two, by putting weights into the opposite scale, and, when the equilibrium is attained, pour gradually the acid into the flask, till an effervescence no longer ensues. When this has ceased, the scale containing the weights will be found to preponderate. This shows that the alkali, by combination with an acid, loses considerably of its weight; and the exact amount of the loss may be ascertained by adding weights to the scale containing the flask and phial, till the balance is restored.

Carbonate of potassa, when exposed to the atmosphere, attracts so much moisture, as to pass rapidly to a liquid state. This change is termed *deliquescence*. All the water thus absorbed is expelled again by a heat of 280°. When submitted, in a crucible, to a high temperature, it fuses; and is volatilized without losing its carbonic acid.

The strongest solution of this salt that can be obtained has the specific gravity 1.54, and contains 48.8 per cent. by weight of carbonate, or 8 atoms of water to 1 of salt.

Hence when an alkali, which should consist almost entirely of carbonate of potassa, is adulterated, as very often happens, with substances of little solubility, the fraud may be detected by trying how much of one ounce will dissolve in two or three ounce-measures of water. In this way I have detected an adulteration of one-third its weight of sulphate of potassa. There are certain substances of ready solubility, however, which may be used in adulterating pearlashes, common salt, for example; and, when this is done, we must have recourse to an acid test for the means of discovery. The best that can be employed for this purpose is sulphuric acid, of sp. gr. 1.141. Of this, 355 grains by weight are equivalent to the saturation of 100 grains of carbonate of potassa. Dissolving, therefore, that quantity of the carbonate in water, and gradually adding the test, so as to produce neutralization, we learn, by the quantity of acid expended, the quantity of real carbonate which has been acted upon; for as 355 to 100, so is the weight of the test which has been used to the number required.

Bi-carbonate of Potassa.

Carbonate of potassa may be much more highly charged with carbonic acid, by exposing a solution of one part of the carbonate in five of water to streams of carbonic acid gas, in a Nooth's machine, or other apparatus; or by the process to be hereafter described. When a solution of alkali, after this treatment, is very slowly evaporated, it forms regular crystals. According to Dr. Wollaston, the quantity of acid in the bi-carbonate is exactly double that in the carbonate. (Phil. Trans. 1808.) This he proves by disengaging the carbonic acid from each by a stronger acid, such as the sulphuric, when one part of the bi-carbonate, considered apart from its water of crystallization, is found to give twice as much carbonic acid as the sub-salt. Berthollet obtained 189 grains of carbonic acid from 500 of this salt; and, as nearly as possible, the same quantity from 1000 grains of the salt, reduced by calcination to the state of carbonate. (Mem. d'Arcueil, ii. 470.) The following Table exhibits the composition of the bi-carbonate, as stated by Vauquelin, and by Dr. Wollaston. One hundred grains contain,

	Acid.	Base.	Water.
According to Dr. Wollaston - - - -	43.9	47.1	9.0
Vauquelin - - - -	47.	46.	7.

The atomic constitution, deducible from these proportions, is 1 atom of potassa = 48, 2 atoms of carbonic acid = 44, and 1 atom of water = 9, in all 101, which last is its representative number.

The BI-CARBONATE OF POTASSA differs from the carbonate in the following particulars:

1. In the greater mildness of its taste. Though still alkaline, yet it may be applied to the tongue, or taken into the stomach, without exciting any of that burning sensation which is occasioned by the carbonate.

2. It is unchanged by exposure to the atmosphere.

3. It assumes the shape of regular crystals.

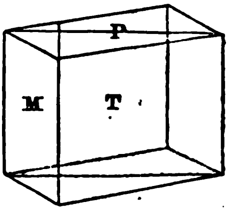
4. It requires, for solution, 4 times its weight of water at 60°; and, while dissolving, absorbs caloric. Boiling water dissolves five-

sixths of its weight; but, during this solution, the salt is partly decomposed, as is manifested by the escape of carbonic acid gas. The quantity thus separated amounts, according to Berthollet, to about $\frac{1}{10}$th the weight of the salt. Döbereiner finds, also, that the crystals, when dissolved in the smallest possible quantity of water, or when covered with water, and left for half an hour in a vacuum, lose one-fourth of their acid.

5. By calcination in a low red heat, one-half of the carbonic acid, and all the water, are expelled, and the salt returns to the state of carbonate. This is the best method of obtaining pure carbonate of potassa for chemical purposes.

The primary form of this substance is *a right oblique-angled prism*, which is not readily traced in the secondary crystals, but may be derived from cleavage, and is shown in fig. 1. There is also a cleavage parallel to a plane passing through the diagonals marked on the terminal planes.

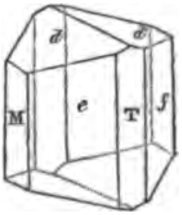
Fig. 1.



P on M, or T	90° 00′
M on the diagonal plane	53 15
M on T	103 25

The planes which appear on the crystals are represented in figure 2; but the planes *e* are sometimes very disproportionately extended, so as nearly to efface T and *f*, giving to the crystals the character of another primary form.

Fig. 2.



The planes T do not commonly occur on the crystals, and without these they nearly resemble a secondary form of the *right rhombic prism;* they may, however, be distinguished by the unequal inclination of M on the two adjacent planes. On cleaving or otherwise breaking the crystal, water may be observed between the laminæ, which probably occasions the measurements on the cleavage not accurately to agree.

This is the case with many other factitious salts.

M on plane parallel to *f*	127° 35′
M on *e*	126 45
T on *e*	156 50
T on *f*	128 50
e on *f*	105 40
M on *d*	111 00
d on *d′*	138 00

(*k*) Bi-carbonate of potassa, in all its forms, is decomposed by the stronger acids; as the sulphuric, nitric, and muriatic, which unite with the alkali, and set the gas at liberty. This may be shown by pouring, on the carbonate contained in a gas bottle, any of the acids, and collecting the gas by a proper apparatus.

Sesqui-carbonate of potassa seems to have been obtained accidentally in a single instance. Its constitution is stated by Dr. Thomson (First Princ. of Chem. ii. 255), to be

1½ atom of carbonic acid - - -	33
1 atom of potassa - - - - - -	48
6 atoms of water - - - - - -	54
	135

The sub-borate of potassa is a salt which is little known. It may be formed by the direct combination of liquid hydrate of potassa with boracic acid.

Phosphite, Phosphate, &c. of Potassa.

Hypo-phosphite of potassa may be formed by the direct combination of its ingredients. It is a deliquescent salt, readily soluble in water, and in alcohol. When heated in a glass tube, phosphureted hydrogen is disengaged; phosphorus is deposited on the inside of the tube; and a yellowish residue is left of phosphate of potassa. (See Rose, Ann. Ch. et Ph. July 1828.)

Phosphite of potassa is a neutral salt, not crystallizable, deliquescent, and very soluble in water, but not in alcohol. When heated, a yellow residue is left, which, with acids, gives a little phosphureted hydrogen.

Phosphate of potassa may be obtained by neutralizing a solution of carbonate of potassa with phosphoric acid, concentrating the solution, and setting it aside for some days to crystallize. (Thomson's First Princ. ii. 256.)

This phosphate has little taste. By the action of heat it undergoes the igneous fusion. The vegetable grains belonging to the *cerealia* contain a small quantity of this salt. It is a compound of 1 atom of phosphoric acid, 1 atom of potassa, and 1 atom of water.

Sub-phosphate of potassa may be obtained by fusing phosphate and hydrate of potassa together in a platinum crucible. It is insoluble in cold, and very sparingly soluble in hot water. It is probably constituted of 2 atoms of potassa and 1 atom of acid.

Bi-phosphate of potassa has been very little examined.

Sulphuret of Potassa.—Hydro-Sulphuret, Hydrogureted Sulphuret, Hyposulphite, and Sulphite of Potassa.

Sulphuret of potassa.—It is unnecessary to add any thing to what has already been said of this supposed compound in the general remarks on sulphurets, page 429, and in speaking of sulphuret of potassium, page 449.

Hydro-sulphuret of potassa may be formed by transmitting a current of sulphureted hydrogen gas through liquid hydrate of potassa, which acquires a yellow colour, and an offensive smell. It forms large transparent crystals, not unlike those of sulphate of soda, but having the shape of four-sided prisms acuminated with four planes, or of six-sided prisms acuminated with six planes. It is deliquescent, and runs into a thick syrupy liquor, which gives a green colour to the skin. It dissolves readily in water and alcohol, with a production of cold. On adding any diluted acid, abundance of sulphureted hydrogen is disengaged, but no sulphur is deposited. Vauquelin found that its solution in water may be evaporated to dryness without decomposing the hydrosulphuret; for on heating the residuum, mixed with sulphur in a retort, sulphureted hydrogen was copiously evolved.

Hydrogureted sulphuret of potassa may be formed by boiling flowers of sulphur in liquid hydrate of potassa, or by digesting sulphur with the liquid hydro-sulphuret. The resulting product may be considered as a compound of bi-sulphureted hydrogen with potassa, in proportions not yet ascertained. By mere solution in water, the sulphuret of potassa is partly changed into this substance. According to Proust, red oxide of mercury, digested with hydrogureted sulphurets, removes the sulphureted hydrogen, and what remains is a pure liquid sulphuret.

Hypo-sulphite of potassa.—This salt is best formed by exposing the hydrogureted sulphuret to the atmosphere, till it has lost its colour, after which, on evaporation, it crystallizes in the form of fine needles; or by decomposing hydro-sulphuret, or hydrogureted sulphuret of potassa, by sulphurous acid. The salt has a taste, at first not unlike that of nitre, succeeded by bitterness, and it is deliquescent. When carefully dried, it takes fire on raising the heat, and burns somewhat like tinder, but with a feeble blue flame. It dissolves chloride of silver, even when very dilute, with great readiness.

Sulphite of potassa may be formed by passing sulphurous acid into a saturated solution of carbonate of potassa, till all effervescence ceases. The solution becomes warm, and crystallizes on cooling in rhomboidal plates, or in small needles diverging from a common centre, which have sometimes a yellowish tinge. It has a pungent and sulphurous taste, and is soluble in an equal weight of cold, or in a less proportion of boiling water. At the temperature of 300° Fahrenheit, it loses only about 2 per cent.; but when more strongly heated, the salt is decomposed, and suffers a loss of about 22 per cent., of which 15 are sulphurous acid, 5 sulphur, and 2 water. When thrown into a red hot crucible, a blue flame arises from it. Its solution, exposed to the air, slowly attracts oxygen, and is converted into sulphate of potassa. From Dr. Thomson's analysis, it is constituted in 100 parts, of 2 water + 54.5 base + 43.5 acid.

Sulphate of Potassa.

Sulphate of potassa.—This salt may be formed by saturating the carbonate of potassa with sulphuric acid, and crystallizing the solution. It is a refuse product, also, of several chemical operations. Its properties are the following:

(*a*) It crystallizes in small six-sided prisms, terminated by six-sided pyramids with triangular faces. The forms of its crystals are represented by Mr. Levy in the Quarterly Journal, xv. 285, and by Mr. Phillips in the Annals of Philosophy, N. S. iv. 340. Its specific gravity, according to Hassenfratz, is 2.0473.

(*b*) It has a bitter taste.

(*c*) It decrepitates when thrown on a red-hot iron, or on red-hot coals, and is volatilized by a strong heat, first running into fusion. By a low red heat it loses very little of its weight, not more than one and a half or two per cent. Indeed it does not essentially contain any water.

(*d*) Water, at 60° of Fahrenheit, takes up only one-sixteenth of its weight; but boiling water dissolves one-fifth, or by continuing the application of heat even one-fourth.

(*e*) The composition of this salt is determined by the quantity of sulphate of baryta, which its solution affords when decomposed by any barytic salt. From 100 parts of the ignited salt, dissolved in water, Dr. Marcet obtained 132 of sulphate of baryta, Berzelius 134.68, and Mr. R. Phillips 136.7. Hence the composition of the salt (reckoning the acid in sulphate of baryta at 33.5 per cent.) is

	Acid.	Base.
According to Dr. Marcet - -	44.22 - -	55.78
———— Mr. Phillips -	45.79 - -	54.21
———— Berzelius - - -	45.0 - -	55.0

There can be no doubt that it is constituted of

1 atom of sulphuric acid - -	40 - - -	45.45
1 atom of potassa - - - - - -	48 - - -	54.55*
Atomic Weight	88	100.

(*f*) Sulphate of potassa is decomposed, at high temperatures, by charcoal, the carbon uniting with the oxygen of the sulphuric acid and with that of the potassa, and escaping in the state of carbonic acid gas. What remains is a compound of sulphur and potassium. No change is effected in sulphate of potassa by fusion with sulphur, which sublimes unaltered.

Sesqui-sulphate of Potassa.

By dissolving and crystallizing the solid mass remaining after the preparation of nitric acid, Mr. R. Phillips obtained, on one occasion, crystals entirely differing in their form both from sulphate and bi-sulphate of potassa. (Ann. of Phil. Dec. 1827.) They were extremely minute filaments resembling asbestos, and being subjected to analysis appeared to consist of

3 atoms sulphuric acid - - - - - -	120
2 atoms potassa - - - - - - - - - -	96
1 atom water - - - - - - - - - - -	9
	225

Bi-sulphate of Potassa.

Bi-sulphate or super-sulphate of potassa may be obtained by dissolving in hot water, the mass which remains in the retort after distilling nitric acid from equal weights of sulphuric acid and nitre. The solution filtered through paper, evaporated, and left to repose, affords crystals of the bi-sulphate. This salt was shown by Dr. Wollaston to contain twice as much acid as the sulphate, with which it may be contrasted as follows:

	Bi-sulphate.	Sulphate.
Potassa - - -	48 or 1 atom - -	48 or 1 atom.
Sulphuric acid	80 or 2 atoms - -	40 or 1 atom.
	128	88

Or we may consider the bi-sulphate as formed of an atom of neutral sulphate and an atom of sulphuric acid.

The bi-sulphate has an intensely sour taste, and a powerful action on blue vegetable colours. One part is soluble in two of water at 60°, and in less than an equal weight at 212°. It is insoluble in alcohol.

Hypo-sulphate of potassa is a salt of which little is known. It crystallizes in cylindroidal prisms, terminated by a plane perpendicular to their axis. (Ann. of Phil. xiv. 355, and Quart. Journ. xv. 285.)

Fluate of potassa.—There are two compounds of fluoric acid and potassa. The *acid fluate* or *bi-fluate* forms square tables with truncated edges, readily soluble in water. By heat it fuses, gives vapour of fluoric acid, and leaves 74.9 per cent. of neutral fluate. It contains 11.6 per cent. of water. It is constituted of 1 atom of neutral fluate and 1 atom fluoric acid. (Berzelius.)

The neutral fluate of potassa is crystallizable, and deliquescent. Its solution, which is alkaline, attacks glass in a day or two, and destroys its polish. When the liquid is rendered neutral by acetic acid, it becomes on farther dilution with water strongly acid, and the vinegar is set at liberty.

Selenites of potassa.—Selenious acid is capable of uniting with potassa in three different proportions, and of composing either a selenite, bi-selenite, or quadri-selenite; but as these salts are not of much importance, I refer for their description to Berzelius's paper in the 9th volume of Ann. de Chim. et de Ph. p. 257, where they are described as seleniates. (See p. 346 of this volume.)

Cyanide of potassa.—Cyanogen is absorbed by liquid hydrate of potassa, and a solution is obtained, which has scarcely any colour unless the cyanogen is in excess, when it becomes brown, and apparently carbonaceous. This solution affords prussian blue when added to an acid solution of iron, carbonic acid escaping, and a smell of hydro-cyanic acid being at the same time perceptible. The volume of carbonic acid produced, it has been shown by Gay Lussac, is precisely equal to that of the cyanogen absorbed, and he has rendered it extremely probable that hydro-cyanic acid and ammonia are at the same time generated.

Hydro-cyanate of potassa may be formed by the mixture of hydro-cyanic acid, and liquid hydrate of potassa. It is very soluble, is alkaline to the taste, and turns syrup of violets green; it is decomposed by the weaker acids, even by the carbonic. With salts having protoxide of iron for a base, it gives a precipitate which is at first orange coloured, and afterwards, by exposure to the air, changes successively to green and to deep blue. From solutions containing peroxide of iron, it causes a pale blue precipitate, the colour of which becomes deeper by exposure to air. When calcined, the acid ingredient abandons its hydrogen, and the salt becomes a *cyanide of potassium*.

Ferro-cyanate of potassa.—When the salt just described is digested in a state of solution with protoxide of iron, a portion of the oxide is dissolved, the solution becomes yellow, and, on adding more hydro-cyanic acid, is rendered neutral, crystallizable, and capable of resisting decomposition by weak acids. But the same compound may be better formed by digesting prussian blue in fine powder with liquid hydrate of potassa. The common prussian blue of commerce should first be heated with an equal weight of sulphuric acid, which has been diluted with five or six parts of water, and then be washed with a large quantity of distilled water. This will remove the alumine which it always contains. After being thus purified, it may be added to the hydrate of potassa, as long as that liquor continues alkaline. The filtered liquor, when evaporated and cooled, deposits crystals, which are quadrangular prisms. These may be purified by a second crystallization.

The ferro-cyanate (formerly called triple prussiate) of potassa is a transparent salt, often in fine large crystals, of a lemon yellow colour, the mathematical form of which is described by Mr. Brooke in the Annals of Philos. N. S. vi. 41, and by Mr. Levy in the Quart. Journ. xv. 288. It is free from taste and smell. Its specific gravity is 1.833. Water at 60° Fahr. dissolves nearly one-third of its weight, and boiling water nearly an equal weight of the salt. When heated, it loses 13 per cent. and becomes white, but does not run into fusion, or undergo decomposition. Submitted to a still higher temperature in a retort, it is decomposed, and yields hydro-cyanic acid and ammonia, beside carbonic acid, carbonic oxide, and carbureted hydrogen; and a residue is left, composed of charcoal, metallic iron, and potassa, which last is still united with more or less cyanogen. (See Robiquet, Ann. de Ch. et de Phys. xvii. 205.)

Diluted acids have little action on ferro-cyanate of potassa, except with the aid of heat, and then the sulphuric, muriatic, and even the acetic acids disengage a certain quantity of hydro-cyanic acid, and occasion a white precipitate, the nature of which is not understood. Red oxide of mercury, digested with a solution of the salt, decomposes it, and gives rise to the formation of cyanide of mercury, and to the disengagement of free alkali, and of peroxide of iron attached to a little acid.

The solution of ferro-cyanate of potassa is not precipitated by alkalies, or by alkaline salts, but is decomposed by some of the earthy, and by almost all the metallic salts. The following Table by M. Thenard shows the colours of the precipitates, thrown down from various solutions, both by the ferro-cyanate, and hydro-cyanate of potassa.

Table of the Colours of Precipitates from Metallic Solutions.

From solutions of salts of	By ferro-cyanate of potassa.	By hydro-cyanate of potassa.
Manganese - - -	White - - - - -	Yellow.
Iron (protoxide) -	White - - - - -	Orange.
—— (deutoxide) -	Pale blue - - - -	Bluish green.
—— (tritoxide) -	Deep blue - - -	Scarcely any.
Tin - - - - - -	White - - - - -	White.
Zinc - - - - - -	Ditto - - - - - -	Ditto.
Cadmium - - -	Ditto - - - - - -	Ditto.
Antimony - - -	Ditto - - - - - -	Ditto.
Uranium - - - -	Blood red - - -	Yellowish white.
Cerium - - - -	White - - - - -	
Cobalt - - - - -	Grass green - - -	Cinnamon.
Titanium - - - -	Reddish brown - -	
Bismuth - - - -	White - - - - -	White.
Copper (protoxide)	Ditto - - - - - -	Ditto.
——— (deutoxide)	Deep brown - - -	Yellow.
Nickel - - - -	Apple green - - -	Yellowish white.
Lead - - - - -	White - - - - -	
Mercury (deutoxide)	Ditto - - - - - -	Yellow.
Silver - - - - -	White, changing to blue - - - - -	White, soluble in an excess of hydro-cyanate.
Palladium - - -	Olive - - - - -	
Platinum - - - -	Yellow - - - -	
Gold - - - - - -	White - - - - -	White, becoming yellow.

Mr. Porrett states the composition of ferro-cyanate of potassa as follows: (Ann. of Phil. xiv. 298.)

Potassa -	40.34 - -	= 1 atom	
Iron - -	11.76 - -	= ½ ditto	forming one atom of ferro-cyanic acid.
Carbon -	20.17 - -	= 4 ditto	
Azote - -	11.76 - -	= 1 ditto	
Hydrogen	.84 - -	= 1 ditto	
Water - -	15.13 - -	= 2 ditto	
	100.		

The ferro-cyanate of potassa has since been analyzed with great care by Berzelius. He decomposed it by heating it with peroxide of copper, and obtained carbonic acid and azotic gases, in the proportions in which they are evolved by the decomposition of cyanogen, *viz.*, 2 volumes of the former and one of the latter. Hence he considers it as a cyanide, and not a prussiate, and deduces its composition to be 2 atoms of cyanide of potassium = 132 + 1 atom of cyanide of iron, = 54, united with 3 atoms of water of crystallization, = 27, making together an atomic weight of 213. This cyanide, in common with all those in which the metal is strongly electro-positive, as those of sodium, barium, &c., he believes to continue such, even after solution in water; while the cyanides with weaker bases, such as those of ammonia, and many of the metallic oxides, become, on the contrary, hydro-cyanates.

The last analysis of the triple prussiate is that of Mr. R. Phillips, published in the Annals of Phil. for February 1827. His results agree very nearly with those of Berzelius, the greatest difference being in the quantity of potassium, which he makes about 0.8 per cent. less, and in that of iron, which exceeds Mr. Porrett's estimate by 1.8 per cent. Reduced to powder, and dried in a moderately hot sand-bath, Mr. Phillips found the loss to be 12.5 per cent. of water. According to the original view of Berzelius, this water pre-existed in the salt; but if the new view of that author, quoted by Mr. Phillips, and already stated in the section on ferro-cyanic acid, be correct, it may be, partly at least, formed during the desiccation. It is less indeed in determining the proportions of the elements of the salt and those of the acid, than in acquiring a just view of the mode in which the elements are combined in each, that the difficulty consists. Mr. Phillips thinks it probable that if the three atoms of water, expelled from the triple salt by heat, do not previously exist in it as such, but are formed by the process, the salt may be regarded as an anhydrous ferro-cyanate of potassa, constituted of

1 atom of ferro-cyanic acid - - - - - -	117
2 atoms of base (potassa) - - - - - -	96
	213

Thus viewed, it is a *di-ferro-cyanate;* but the experiments promised by Mr. Phillips will, it is to be hoped, clear up the obscurity that still prevails on this subject.

Combination of chlorine with prussiate of potassa.—By passing chlorine gas through a solution of prussiate of potassa, Gmelin obtained a dark greenish yellow liquid, from which regular crystals were procured by evaporation. These he considered as a cyanide of iron and potassium. Mr. J. F. W. Johnston adopted a different method, and over prussiate of potassa carefully deprived of its water of crystallization, in which state it is white, passed chlorine for several days. The white powder became of a beautiful bright yellow colour, and its solution in water which had a similar colour, gave, on evaporation, crystals partly red and partly yellow, the first being a new salt, the latter common prussiate. When the pulverized crystals of common prussiate are similarly treated, they lose their 3 atoms of water, and chlorine is absorbed as before. The composition of the new salt is stated by Mr. Johnston as follows:

2 atoms anhydrous prussiate of potassa - -	372
1 atom chlorine - - - - - - - - - - -	36
	408.

The view of the constitution of this compound, which Mr. Johnston is most disposed to take, is, that it consists of 1 atom chloro-ferro-cyanic acid (248) + 4 atoms potassium (160), its atomic weight being the sum of these numbers, 408. The acid in the above salt he regards as containing neither oxygen nor hydrogen; but its further investigation will be the object of Mr. Johnston's future experiments. It forms salts, all of which have a deep red colour, and are more or less combustible. (Edin. Phil. Trans. 1828.)

SECTION II.

Sodium.

Sodium was discovered in 1808 by Sir H. Davy. It is procured by a process exactly resembling that employed in preparing potassium, with this obvious difference, that hydrate of soda must be substituted for that of potassa. In its external characters and chemical properties, it bears a near resemblance to potassium, and it is chiefly by examining the results of its action, that we discover its differences from the latter metal.

I. Sodium, at common temperatures, exists in a solid form. It is white, opaque, and, when examined under a thin film of naphtha, has the lustre and general appearance of silver. It is exceedingly malleable, and much softer than any of the common metallic substances. When pressed upon by a platinum blade with a small force, it spreads into thin leaves; and a globule of $\frac{1}{10}$th or $\frac{1}{12}$th of an inch in diameter is easily spread over a surface of a quarter of an inch. This property is not diminished, by cooling it to 32° Fahrenheit. Several globules, also, may, by strong pressure, be forced into one; so that the property of *welding*, which belongs to platinum and iron at a high degree of heat only, is possessed by this substance at common temperatures.

II. It is lighter than water. As near as can be determined, its specific gravity is as 0.972 to 1.

III. It is much less fusible than the base of potassa. At 120° Fahrenheit, it begins to lose its cohesion, and it is a perfect fluid at 180° or 190°. Hence it readily fuses under heated naphtha.

IV. Its point of vaporization has not been ascertained; but it remains fixed, in a state of ignition, at the temperature of fusion of plate glass.

V. When SODIUM is exposed to the atmosphere, it immediately tarnishes, and by degrees becomes covered with a white crust of soda, which deliquiates more slowly than that formed on potassium. It is not changed, however, by air that has been artificially dried.

VI. It combines with oxygen, slowly and without luminous appearance, at all common temperatures. When heated to its fusing point, the combination becomes more rapid; but no light is emitted till it becomes nearly red-hot. The flame, which it then produces, is white, and it sends forth bright sparks, exhibiting a very beautiful effect. In common air, it burns with a similar colour to charcoal, but with much greater splendour.

VII. When thrown into water, it produces a violent effervescence and a loud hissing noise; it combines with the oxygen of the water to form soda; and hydrogen gas is evolved, which does not, however, as in the case of potassium, hold any of the alkaline base in solution. Neither can sodium be made to dissolve in hydrogen gas, by being heated in contact with it.

When thrown into hot water, the decomposition is more violent, and in this case a few scintillations are generally observed at the surface of the fluid; but this is owing to small particles of the base, which are ejected from the water, sufficiently heated to burn in passing through the atmosphere.

VIII. Its action on alcohol, ether, volatile oils, and acids, is similar to that of potassium; but with nitric acid a vivid inflammation is produced.

IX. Sodium appears to be susceptible of different degrees of oxidation. 1st. When it is fused with dry soda, a partition of oxygen takes place between the alkali and the metal. A deep brown fluid is produced, which becomes a dark grey solid on cooling. This substance is capable of attracting oxygen from the atmosphere, and of decomposing water, by which it is again converted into soda. The same *sub-oxide* of *sodium* is formed, by fusing this metal in tubes of plate glass. It is of a greyish colour, destitute of lustre, brittle, and gives hydrogen when acted on by water, but less than an equal weight of sodium. It may, however, be doubted, whether this is a compound of sodium and oxygen, or merely a mixture of the metal with soda. The latter opinion appears to me the more probable.

2d. The next oxide of sodium is *soda*. It may be formed by burning sodium in a quantity of air, containing just oxygen enough to convert the metal into alkali. It is of a grey colour; of a vitreous fracture; and requires a strong red heat for its fusion. This, indeed, may be considered as the true protoxide of sodium, constituted, according to Gay Lussac and Thenard, of 100 metal + 33.995 oxygen; or, according to Berzelius, of 100 of the former + 34.372 of the latter. Sir H. Davy, from a variety of experiments, concluded that soda is a compound of from 73 to 75 sodium with from 27 to 25 oxygen, and in one instance obtained exactly the numbers 75 and 25, or 3 of sodium to 1 oxygen. Indirect experiments on the salts of soda tend, also, to show that in its anhydrous state, soda is constituted of

1 atom of sodium - - - - - - - -	24
1 atom of oxygen - - - - - - - -	8
Atomic weight -	32

When the protoxide is brought into contact with water, it absorbs it with great heat, and cannot be again separated from it, except by some substance which it attracts still more powerfully. Even after fusion, the soda is still a hydrate, containing 1 atom of protoxide = 32, + 1 atom of water = 9, together 41. Hydrate of soda contains, therefore, 22$\frac{1}{4}$ per cent. of water, which considerably exceeds the proportion in the similar compound of potassa.

The following table by Mr. Dalton shows the proportion of real soda, free from water, in solutions of different specific gravities.

The first liquid compound is that which consists of 1 atom of soda + 2 atoms of water.

Table of the Quantity of Real Soda in watery Solutions of different Specific Gravities.

Atoms of soda water.	Soda per cent. by weight.	Soda per cent. by measure.	Specific Gravity.	Congealing point.	Boiling point.
1 + 0	100	230?	2.30?	unknown.	unknown.
1 + 1	77.8	156	2.	1000°	red hot.
1 + 2	63.6	118	1.85	500°	600°
1 + 3	53.8	93	1.72	250°	400°
1 + 4	46.6	76	1.63	150°	300°
1 + 5	41.2	64	1.56	80°	280°
1 + 6	36.8	55	1.50		265°
	34	50	1.47		255°
	31	45	1.44		248°
	29	40	1.40		242°
	26	35	1.36		235°
	23	30	1.32		228°
	19	25	1.29		224°
	16	20	1.23		220°
	13	15	1.18		217°
	9	10	1.12		214°
	4.7	5	1.06		213°

3d. The peroxide of sodium may be formed, by burning the metal with an excess of oxygen gas. It is of a deep orange colour, very fusible, and a non-conductor of electricity. When acted on by water, its excess of oxygen escapes, and it becomes soda. It deflagrates with most combustible bodies. It appears to be constituted of 2 atoms of sodium = 48, with 3 atoms of oxygen = 24, and its equivalent number is therefore 72.

Chloride of Sodium.

Sodium burns in chlorine gas, and is converted into a white solid, having a penetrating taste. The same compound results from heating sodium strongly in muriatic acid gas, the hydrogen of which is liberated, while the chlorine combines with the metal. Or it may be formed by saturating carbonate or hydrate of soda with muriatic acid, and evaporating the liquid, which yields chloride of sodium in a solid form. This chloride, also, is an abundant product of nature, being that well-known substance, common salt, which is become a necessary ingredient in the food of man, and is of essential utility in several of the arts. For purposes of experiment, the common salt may be employed, which is usually met with under that name. This may be purified by adding, to a solution of it in cold water, a solution of carbonate of soda, as long as any milkiness ensues; filtering the solution, and evaporating it till it crystallizes.

II. Its qualities are as follow:

1. It crystallizes in solid regular cubes, or, by hasty evaporation, in hollow quadrangular pyramids, which, when the salt is pure, are but little changed by exposure to the air. The common salt of the shops, however, being impure, acquires an increase of weight, in consequence of the absorption of moisture. The various forms under which it appears, of stoved salt, fishery salt, bay salt, &c. arise from modifications in the size and compactness of the grain, rather than from any essential difference of chemical composition, as I have shown in a memoir published in the Phil. Trans. for 1810.

2. It requires, for solution, twice and a half its weight of water, at 60° of Fahrenheit, and hot water takes up very little more. Hence its solution crystallizes, not like that of nitre, by cooling, but by evaporation.

3. When heated gradually, it fuses, and forms, when cold, a solid compact mass.

4. If suddenly heated, as by throwing it on red-hot coals, it decrepitates. It does not, however, after being dried at the temperature of boiling water, lose by ignition more than two or three parts of water *per cent.*, and essentially it contains no water.

5. It is not decomposed when ignited in contact with inflammable substances, except with potassium, which sets at liberty half its weight of sodium.

6. When mixed with powdered charcoal or sulphur, and fused in a crucible, it does not undergo any decomposition or essential change.

7. It is decomposed by the carbonate of potassa, the alkali of which combines with the muriatic acid of the salt, and the carbonic acid is transferred to the soda.—Hence we obtain chloride of potassium and carbonate of soda. A process for effecting this decomposition, on a large scale, is described by Westrumb, in Crell's Journal, English translation, ii. 127.

8. It is decomposed by the sulphuric acid in the mode already described (p. 243). Nitric acid, and other acids, also separate the muriatic acid.

When chloride of sodium is dissolved in water, it passes, by the decomposition of that fluid, to the state of muriate of soda, and it is this salt, and not the chloride of sodium (which last can only exist in a solid form) that is the ingredient of sea water and other solutions of common salt. Muriate of soda is composed, in 100 grains,

		Acid.	Base.
According to Darcet - - -	of - - -	49.27 -	50.73
———— Berard - - -	— - - -	43. -	57.
———— Dr. Marcet -	— - - -	46. -	54.
———— Berzelius - -	— - - -	46.56 -	53.44

From 100 grains of transparent rock salt, dissolved in water, and precipitated by nitrate of silver, I obtained 242 of luna cornea; Dr. Marcet, from 100 grains of pure artificial muriate of soda, fused before solution, obtained 241.6; Berzelius 244.6; and Rose 245.4. Now 100 grains of luna cornea may be stated, in round numbers, to denote 24.65 grains of chlorine, so that it is easy, from this datum, to calculate the composition of common salt, or of any chloride, which has been decomposed by nitrate of silver.

When, again, we expel the water from a solution of common salt, we re-produce the chloride of sodium, so that muriate of soda can have no existence except in a fluid state. Chloride of sodium, as it exists in fused common salt, is constituted of an atom of sodium, weighing 24, with an atom of chlorine weighing 36, and its equivalent is 60. It consists, then, of

Sodium	40.5	24
Chlorine	59.5	36
	100.	Atomic weight 60

Dr. Wollaston assumes its constitution to be either 39.64 sodium + 60.36 chlorine; or, on the old theory of muriatic acid, he admits its composition as formerly stated by Berzelius, who has since, however, adopted the opinion of its being a chloride.

To obtain chlorine from this salt, we must take

1 atom chloride of sodium (*viz.* 24 sodium + 36 chlorine) = 60
1 atom peroxide manganese (28 mang. + 16 oxygen) = 44
2 atoms real sulph. acid (40 × 2 = 80) or 2 oil of vitriol (49 × 2 = 98) - - - - - = 98

Of the 2 atoms of sulphuric acid, 1 atom acts upon the oxide of manganese, from which it expels 1 atom of oxygen, 8, leaving 1 atom of protoxide, 36, to unite with the atom of sulphuric acid. We have, therefore, 40 + 36 = 76 protosulphate of manganese. The disengaged atom of oxygen, with 24 of sodium, forms 32 soda, which, with the other atom of sulphuric acid, composes 32 + 40 = 72 sulphate of soda. The chlorine of the 60 parts common salt = 36, or 1 atom, escapes in a gaseous state.

Sodium and Iodine.

The action of *sodium* and *iodine* on each other is so analogous to that of potassium and iodine, that it is unnecessary to describe it. Iodide of sodium is obtained, and this compound, when made to act on water, forms both iodate and hydriodate of soda.

No combination is yet known of sodium and *hydrogen.*

On *azotic gas* sodium appears to have no action, but, when heated in ammoniacal gas, hydrogen is disengaged, and a nitruret of sodium is formed, which has an olive green colour, is fusible at a low heat, and according to the experiments of Gay Lussac and Thenard, is composed of 100 parts of sodium and 11.728 nitrogen.

Phosphuret and Sulphuret of Sodium.

There is scarcely any difference between the visible phenomena attending the action of the base of soda and that of potassa on sulphur, phosphorus, and the metals. The sulphuret of sodium has a deep grey colour; the phosphuret resembles lead.

Amalgam of Sodium and Mercury.

Added to mercury in the proportion of $\frac{1}{40}$th, sodium renders that metal a fixed solid of the colour of silver, and the combination is attended with a considerable degree of heat. This amalgam seems, like that of potassium, to form triple compounds with other metals, even with iron and platinum, which remain united with the mercury, when it is deprived of the new metal by the action of air.

Salts of Soda.

Chlorate of soda.—This salt may be obtained by following the process already described, with the substitution of pure soda for potassa; or, by adding chloric acid to carbonate of soda, till the effervescence ceases. It is exceedingly difficult, however, to obtain it pure by the first process, because it nearly agrees in solubility with the common muriate of soda; and the second method is therefore preferable. It is soluble in three parts of cold water, and in rather less of hot, and is slightly deliquescent. It is soluble also in alcohol; but so also, according to M. Chevenix, is the chloride. It crystallizes in cubes, or in rhomboids approaching the cube in form. In the mouth it produces a sensation of cold, and a taste scarcely to be discriminated from that of muriate of soda. In other properties it agrees with the similar salt with base of potassa.

Iodate and hydriodate of soda.—Both these salts are obtained by agitating iodine with liquid hydrate of soda. The iodate has the form of small grains which have a cubical shape; contain no water of crystallization; and, when heated, yield oxygen gas, a little iodine, and an iodide of sodium. They contain 84.1 iodic acid, and 15.9 soda.

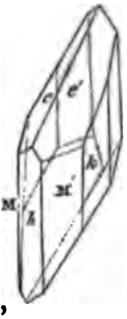
Hydriodate of soda crystallizes in flattened rhomboidal prisms, which are deliquescent, and contain much water of crystallization. By a sufficient heat it is converted into iodide of sodium; of this iodide, 100 parts of water at 60° Fahr. dissolve 173 parts, and, when strongly heated, it becomes slightly alkaline, and is volatilized. The hydriodate of soda is composed of 100 parts hydriodic acid, and 24.728 soda.

Nitrate of soda.—This salt may be formed by saturating carbonate of soda with nitric acid, or by distilling common salt with three-fourths its weight of nitric acid. When the former process is adopted, the solution must be evaporated, till a pellicle appears on its surface, and then allowed to cool. Crystals will be produced, the shape of which is described by Mr. Brooke, Ann. of Phil., N. S., v. 452.

These crystals have a taste like that of saltpetre, but more intense. They are soluble in three parts of water, at 60°, and in less than an equal weight of boiling water. They attract moisture from the atmosphere. In other respects they agree with the nitrate of potassa. The only use of nitrate of soda is, perhaps, that which has been suggested by Proust, who has found it to be more economical in the making of fire-works than nitrate of potassa. (Nicholson's Journal, xv. 262. See also 6 Ann. de Chim. et Phys. 206.) It consists, according to Dalton, of 57.6 acid = 42.4 base; but these proportions do not exactly agree with those which ought to be its ingredients, if constituted of an atom of base + 1 atom of acid, and if free from water, as asserted by M. Longchamp.

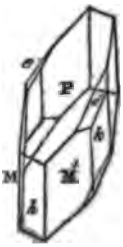
Carbonate of Soda.

There are three distinct compounds of carbonic acid and soda. The first, called sometimes the *sub-carbonate*, a name, however, which is less appropriate in this case than that of *carbonate*, is obtained by carefully re-crystallizing the soda of commerce. When required of great purity, it is best prepared either from pure acetate of soda, which is decomposed at a red heat, and converted into carbonate of soda and charcoal, the former of which is separable by water; or it may be obtained still more pure by calcinating the bi-carbonate.



Its primary form was described by Romé de L'Isle, from an inaccurate measure of the angles, as an *octahedron with a rhombic base.* The annexed figure represents the common form of the crystals.

P on M, or M′	108° 43′
P on e, or e′	129 52
P on h	121 20
M on M′	76 12
M on h	128 6
M on k	141 54
e on e′	79 44
e on k	140 8



By dissolving and re-crystallizing the large crystals, others resembling fig. 2 were obtained. These were much reduced in height, and some of them were so thin as to leave scarce a vestige of the planes M and *h*: several were hemitropes, the plane of imaginary section being parallel to P. The primary form may therefore be considered as an oblique rhombic prism. (Brooke, Ann. of Phil., N. S., vi. 287.)

These crystals have the following properties:

1. When heated to 150° Fahrenheit, they fuse; then boil violently, if the heat be raised; and leave a dry white powder. What escapes is water only; and it forms, according to Berard, 62.69 per cent. of the weight of the salt; to Kirwan, 64; Dalton, 63; and D'Arcet, 63.6. The crystals, also, lose their water by exposure to the atmosphere, or *effloresce*, but they are not in this way deprived of all their water of crystallization.

2. If the fused salt be kept boiling in a retort, Mr. Dalton finds that it deposits a hard small-grained salt, which contains only 46 per cent. of water; the clear liquid has the specific gravity of 1.35; and, on cooling, concretes into a fragile icy mass. The first com-

pound Mr. Dalton estimates to consist of 1 atom of carbonate, and 10 of water; the second of 1 atom of salt, and 5 of water; and the third of 1 atom of salt, and 15 of water.

3. Water at 60° takes up half its weight of the sub-carbonate; and boiling water dissolves rather more than its own weight. The strongest solution that can be preserved at the temperature of the atmosphere has the specific gravity 1.26; but even this is liable to partial crystallization.

4. If 100 grains of the salt be slowly added to a quantity of diluted sulphuric acid more than sufficient for neutralization, and of known weight, the loss of weight will show the quantity of carbonic acid contained in 100 grains. From experiments of this kind, joined with others on its loss by fusion, Berard deduces its composition to be

Acid - -	13.98	- 100 -	60
Base - -	23.33	- 166 -	100
Water - -	62.69		
	100.		

Independently of the water of crystallization, its composition is,

Carbonic acid -	41.23	or 1 atom	= 22
Soda - - - -	58.77	or 1 atom	= 32
	100.	Atomic weight	54

And the crystals consist of

Carbonate of soda -	37.5	or 1 atom -	54
Water - - - -	62.5	or 10 atoms	90
	100.	Atomic weight	144

As 100 grains of the anhydrous carbonate neutralize 460 of sulphuric acid of density 1.141, it is easy to learn the quantity of dry carbonate in any specimen of soda of commerce, provided it be free from other alkalies, by ascertaining the proportion of sulphuric acid of that density which is neutralized by 100 grains of the sample; for, as 460 to the acid neutralized, so is 100 to the number required.

Bi-carbonate of Soda.

When a weak solution of the carbonate of soda is saturated, by passing through it a stream of carbonic acid gas, or when in a solution of 100 parts of the salt we dissolve 14 parts of carbonate of ammonia, we obtain, by evaporation at a gentle heat, an indistinctly-crystallized salt, which is the *bi-carbonate of soda.* The taste of this salt is much milder than that of the carbonate; and it requires between nine and ten times its weight of water at 60° F. for solution. This solution cannot be much heated without driving off part of the carbonic acid, and the same effect is produced by exposing the solution, or the moistened salt, in a vacuum. It affects colour tests in the same manner as the sub-carbonate. One hundred grains, by exposure to a low red heat, lose 37.4, and 62.6 grains of anhydrous carbonate remain. Its constitution is

Carbonic acid -	57.9	or 2 atoms	44
Soda - - - -	42.1	or 1 atom	32
	100.		76

There is a disagreement in the various statements of its proportion of water. According to Berard, 100 grains contain 20.2, which would indicate very nearly 2 atoms of water. Dr. Thomson, from his own analysis, gives the following, which appears to me the more probable constitution:

Bi-carbonate -	89.4	or 1 atom	76
Water - - -	10.6	or 1 atom	9
	100.		85

Sesqui-carbonate.—A native carbonate of soda, found near Fezzan, in Africa, and there called *trona*, has been analyzed by Mr. R. Phillips. He ascertained it to be a compound intermediate between the carbonate and bi-carbonate, or to be constituted of 3 atoms of acid + 2 of soda, or of 1½ atoms of acid = 33, + 1 of soda = 32, together 65. Hence he has given it the name of ***sesqui-carbonate of soda.*** (Quart. Journ. vii. 298.)

The salt sold as bi-carbonate he finds to be a compound of an atom of carbonate and an atom of bi-carbonate, or to consist of

Carbonic acid	39.76	or 3 atoms =	66
Soda - - -	38.55	or 2 atoms =	64
Water - - -	21.69	or 4 atoms =	36
	100.	Weight of its atom.	166

The so called bi-carbonate of the shops is, therefore, a sesquicarbonate, combined with water.

Compound Carbonate and Chloride of Soda.—Disinfecting Liquid of Labarraque.

Either of these names may be given provisionally to the *disinfecting soda liquid*, invented by Labarraque, the process for which is thus described by Mr. Faraday. (Quart. Journ., N. S., No. 3.)

Dissolve 2800 grains of crystallized carbonate of soda in 1.28 pints of water, and place the solution in a Woulfe's apparatus. Pass through it two-thirds of the chlorine, evolved from a mixture of 967 grains of common salt, with 750 grains of oxide of manganese, acted upon by 967 grains of sulphuric acid, previously diluted with 750 grains of water. The remaining one-third of the chlorine is partly absorbed by the water of the balloon through which the gas is passed, and partly remains in the open space of that vessel and of the retort. The distillation must be carried on at the gentlest possible heat. The chlorine is readily absorbed by the alkaline carbonate, and, what is remarkable, without the escape, when the above proportions are used, of a particle of carbonic acid, from the beginning to the end of the process.

The product is a liquid of a pale yellow colour, with but little odour of chlorine. Its taste is at first sharp and saline, scarcely at all alkaline, but with a persistent astringent biting effect on the tongue. It first reddens turmeric paper, and then bleaches it. When boiled out of contact with air, it gives out no chlorine, which, though ready to bleach and to disinfect, cannot therefore be in the state of ordinary solution, for then it is easily expelled by heat. The liquid may even be evaporated to the state of moist crystals, which still retain the taste, smell, &c. of the original solution, with almost equal strength. By this treatment, a similar solution, with the full proportion of chlorine, would be converted almost entirely into chlorate of soda and chloride of sodium. By evaporation, however, in an open basin, the chlorine is almost as perfectly separated from the soda liquid as by an acid. By simply keeping the liquid 43 days in a stoppered bottle, in an obscure place, there was also a gradual re-action of the chlorine, and a formation of the usual products.

Carbonic acid does not appear to have the power of displacing chlorine from this liquid, except in very small quantity, even when a quantity equivalent to 1300 times the volume of the liquid is made to pass through it.

The constitution of this liquid cannot, then, be considered as clearly understood. But it is well ascertained that the chlorine exists in a state of combination strong enough to occasion its being retained in considerable quantity, but not strong enough to prevent its disengagement with sufficient facility to serve the purpose of a valuable disinfectant. Berzelius has given an explanation of the decolouring compounds of chlorine, which rests on the supposition that they contain an acid of inferior oxidation to the chloric, which he calls the *chlorous*. But, till the existence of such an acid has been proved, we are not entitled to assume it to explain chemical phenomena. (See Ann. de Ch. et de Ph. xxxviii. 216.)

For information and directions respecting the medicinal use of the chlorides, I refer the reader to a separate work on the subject by Mr. Alcock, of London.

Borate of Soda.

This salt is imported in a crude state from India under the name of *tincal*, which, when purified, becomes the *refined borax* of the shops. It crystallizes in prisms with six irregular sides; effloresces in the air; fuses when ignited; then loses its water of crystallization, and is changed into a white powder, which, on increasing the heat, leaves a transparent mass, called *glass of borax*, a substance of great use in experiments with the blow-pipe. The crystallized salt dissolves in 20 parts of water at 60°, and in 6 parts of boiling water. It changes the colour of syrup of violets to green, and was therefore considered as a sub-salt. The following is its composition according to Gmelin (Ann. of Phil. ix.), and to Dr. Thomson (First Princ. i. 167):

	Acid.		Base.		Water.	
According to Gmelin - - -	35.60	-	17.80	-	46.6	= 100
Thomson - -	31.58	-	20.42	-	48.0	= 100
Berzelius - -	36.59	-	16.31	-	47.1	= 100

Having determined the atomic weight of boracic acid, from the combinations of fluoboric acid, to be 24, Dr. Thomson deduces the constitution of borate of soda (or *bi-borate*, as it should, under this view, be termed,) to be,

2 atoms of boracic acid - - = 48
1 atom of soda - - - - - - = 32
8 atoms of water - - - - - = 72
152

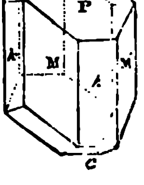
A new variety of borax was obtained, at first accidentally, by M. Payen, who, by carefully observing the circumstances under which it was formed, is now able to produce it at pleasure. It contains the same relative proportions of acid and base as common borax, but only 5 atoms of water, or half the quantity which M. Payen finds in common borax. The new borax is in regular octahedrons; has the sp. gr. 1.815, instead of 1.74; is not rendered brittle by the sudden application of 30° or 40° of heat; and is harder than the ordinary kind. In soldering, it will probably supersede the old sort, because it swells less and flows more readily. It is produced by dissolving, in boiling water, as much common borax as will give a solution of sp. gr. 1.246. If this be left to cool gradually, small octahedral crystals begin to form at 174° Fahr.; and these increase in size and number until the temperature is 133°, when the liquid must be poured off. (Quart. Jour. N. S. iii. 483.)

Phosphite and Phosphate of Soda.

Phosphite of soda has not been examined. *Hypo-phosphite of soda* is very soluble in water and alcohol. Little else is known respecting it. (See Ann. de Ch. et de Phys. ii. 142.)

Phosphate of soda may be obtained by saturating with carbonate of soda the phosphoric acid obtained from bones (see p. 323), and evaporating the filtered liquor till a pellicle appears. On cooling, crystals are formed, the primary form of which is an oblique rhombic prism, with indistinct cleavages parallel to the planes M and M′. The crystals are frequently deposited singly, and are very symmetrically formed.

P on M, or M′ - - - - - -	106°	44′
P on *c* - - - - - - - -	129	12
P on *g* - - - - - - - -	112	27
P on *h* - - - - - - - -	121	14
M on M′ - - - - - - - -	67	30
M on *h* - - - - - - - -	123	45
M on *k* - - - - - - - -	146	15



The crystals are soluble in four parts of water at 60° Fahr., or in twice its weight of water at 212°. The salt contains always an excess of base, and effloresces rapidly when exposed to the atmosphere. It does not, however, lose the whole of its water; for, after three months' exposure, Gay Lussac found that 7.4 proportions remained out of 12, and, being again exposed during thirteen days of hot and dry weather, 6.5 proportions were still discovered. (An. de Ch. et de Ph. xxxiv. 334.) By a strong heat it loses 62 per cent., or rather more, of water, and the residuum is fusible into an enamel. The dry salt is constituted (Berzelius, Ann. de Chim. et de Phys. ii. 164,) of

Phosphoric acid	53.48	100
Soda	46.52	87
	100.	

These proportions are nearly reversed by Dr. Thomson (First Princ. i. 201), who states the anhydrous salt to consist of

Phosphoric acid,	1 atom	= 28	or 46.67
Soda	1 atom	= 32	or 53.33
Atomic weight		60	100.

And the crystals (in which Gay Lussac agrees) generally of

Phosphoric acid,	1 atom	= 28	16.39
Soda	1 atom	= 32	18.73
Water	12 atoms	= 108	64.88
Atomic weight		168	100.

Mr. Dalton considers the salt above described as a *bi-phosphate*, constituted of 2 atoms of acid and 1 of base. To render it neutral to colour-tests, he finds that the acid must be doubled, or that the neutral phosphate is, in fact, a *quadri-phosphate*. The simple phosphate, consisting of 1 atom of acid and 1 of base, may be formed by adding as much more caustic soda to the bi-phosphate as it already contains. The new salt is much more soluble than the bi-phosphate, and crystallizes in very fine needles. This salt Mr. Dalton recommends as the proper re-agent in chemical analysis. (Manch. Memoirs, N. S., iii. 11.)

A very different atomic constitution of this salt, so far as respects its water, has been assigned by Mr. Clark, of Glasgow, (Brewster's Journ., No. 14,) who states the proportions of water to be 25 to 1 proportion of the salt. A concentrated solution, he adds, exposed to a temperature of 90° Fahr. in a stove, yields crystals containing only 15 proportions of water.

Pyro-phosphate of Soda.

This name has been given, by Mr. Clark, of Glasgow, to phosphate of soda which has been subjected to a red heat. By this treatment, not only its water is expelled, but the salt appears to undergo some change of constitution; for its solution gives with nitrate of silver, not a yellow precipitate like that of the common phosphate, but a white one; and, when wholly decomposed by the salt of silver, the remaining solution is neutral, not acid, as when the common phosphate has been decomposed. Yet no gaseous or other product can be collected except water. The crystallized phosphate was found to contain, to each proportion, 25 proportions of water, of which 24 were separated by a sand-heat, and 1 by a red heat. The salt had then acquired the new properties which have been just described; and, from its solution in water, crystals were obtained, obviously different in form from those of common phosphate of soda, and containing only 10 proportions of water.

These facts, if correctly observed, can only be explained by supposing a new arrangement of the elements of the phosphate, occasioned by the high temperature to which it has been exposed. (See Brewster's Edinb. Jour. No. xiv. p. 299.)

Sulphuret of Sodium.—Hydro-sulphuret, Hydrogurreted Sulphuret, Hypo-sulphite, and Sulphite of Soda.

Sulphuret of sodium has been formed, and its composition established, by Berthier, by cementing sulphate of soda with charcoal. It is constituted of

1 atom of sulphur - - - - -	16
1 atom of sodium - - - - -	24
	40

Its properties are, for the most part, analogous to those of sulphuret of potassium, when acted upon by water and acids.

Hydrogurreted sulphuret of soda derives its chief importance from being produced, along with the carbonate, in several processes, by which soda is obtained from the sulphate. (Ann. de Chim. lxiv. 59.) When first formed, it is transparent, colourless, and crystallizes in four-sided prisms acuminated by four planes. It has an acrid and alkaline taste, which soon changes to a strong bitter. Its solution is colourless, but tinges the skin and paper green. With acids it effervesces briskly, sulphureted hydrogen escapes, and no sulphur is deposited, unless chlorine or nitric acid be added, which attract the hydrogen, and throw down sulphur.

Dr. Thomson has examined it, and finds it to consist of

1 atom of bi-sulphureted hydrogen - - -	33
1 atom of soda - - - - - - - - - - -	32
6 atoms of water - - - - - - - - - -	54
	119

When sulphurous acid is passed through the solution of this salt, as long as the acid continues to lose its smell, one-half of the sulphur contained in the salt is precipitated, and in the liquid nothing is left but hypo-sulphite of soda, which admits of being crystallized. (Phil. Trans. 1826.)

To distinguish this hydro-sulphuret from that of potassa, which it closely resembles, Vauquelin proposes to add a solution of alumine in sulphuric acid. This occasions a crystallization of alum with the latter, but not with the hydro-sulphuret of soda.

Sulphite of soda forms white and transparent crystals, which are four-sided prisms, with two broad sides and two narrow ones, terminated by dihedral summits. It has a cool sulphurous taste, is soluble in four parts of cold, or in less than its weight of boiling water. By exposure to the air, it effloresces, and is changed into a sulphate. It is constituted, according to Dr. Thomson, of

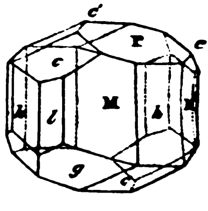
Acid - - - - - -	24.5	or 32	= 1 atom
Soda - - - - - -	24.5	or 32	= 1 atom
Water - - - - -	51.	or 63?	= 7 atoms?
	100.		

Hypo-sulphite of soda may be prepared in the same way as the analogous salt of potassa. When the solution is evaporated to a syrupy consistence, it crystallizes in silky tufts, radiating from a centre, and rendering the liquid solid. It is deliquescent, and its taste is intensely bitter and nauseous. When heated, it first fuses, then dries into a white mass, and at length takes fire and burns with a bright yellow flame. It is insoluble in alcohol. It has the property of rapidly dissolving the chloride of silver, when newly precipitated.

Sulphate of Soda.—Glauber's Salt.

(*a*) This salt forms regular crystals, in which, however, no distinct cleavage can be found. Its primary form is an oblique rhombic prism.

P on M, or M′ - - -	101°	20′
P on *e*, or *e*′ - - - -	133	18
P on *h* - - - - -	107	44
P on *c* - - - - - -	130	45
M on M′ - - - - -	80	24
M on *h* - - - - -	130	12
M on *l* - - - - -	162	38
M on *k* - - - - -	139	48



(*b*) It has a more bitter taste than the preceding sulphate, and dissolves more easily in the mouth.

(*c*) It melts and swells upon a heated iron, in consequence of the loss of its water of crystallization, and a white powder is left, amounting to 43.2 parts from 100 of the original salt, according to Bucholz.

(*d*) By exposure to the atmosphere, it effloresces, and loses weight; and with so much quickness, that it is difficult to ascertain precisely its water of crystallization. Berzelius states it at 56 per cent., which agrees with my experience. Gay Lussac finds that it is thus entirely deprived by efflorescence of its water of crystallization.

(*e*) It is very soluble in water, three parts of which, at 60° of temperature, dissolve one of the salt; and boiling water dissolves its own weight.

(*f*) Its composition is inferred from the quantity of sulphate of baryta, obtained by decomposing the solution of a known weight of this salt by any barytic salt; for 100 grains of anhydrous sulphate of baryta contain 33.9 sulphuric acid. In this way it has been proved to consist of

Sulphuric acid -	55.55	- or 1 atom =	40
Soda - - - - - -	44.45	- or 1 atom =	32
	100.	Weight of its atom	72

And the crystals are composed of

Sulphuric acid - -	24.70	- - - - or 1 atom =	40
Soda - - - - - -	19.75	- - - - or 1 atom =	32
Water - - - - - -	55.55	- - - - or 10 atoms =	90
	100.	Weight of its atom	162

An anhydrous variety of this salt has been described by Dr. Thomson. (Ann. of Phil. 2d Ser. xii. 401.) Its formation depends merely on the difference of temperature at which evaporation is carried on. It takes place, also, when hydrated crystals of Glauber's salt are carefully melted; a portion dissolves, and a portion separates, the latter in an anhydrous state. (Quart. Journ. 2d Ser. iii. 223; see also Ann. de Ch. et de Ph. xxxvii. 204.)

Bi-sulphate of soda may be formed by adding sulphuric acid to a hot solution of sulphate of soda. Large rhomboidal crystals are formed, which are soluble in twice their weight of water at 60°; effloresce by exposure to the air; and when heated lose their excess of acid.

Seleniates of soda.—Selenic unites with soda, and constitutes a distinct salt. (See Mitscherlich, Ann. de Ch. et Ph. May, 1828.)

Hydro-cyanate of soda, like all the other salts of this class, is alkaline, and is decomposed by mere exposure to the atmosphere.

Ferro-cyanate of soda is of a yellow colour, and forms four-sided prisms, terminated by dihedral summits, which effloresce in the air, and lose 37½ per cent. of their weight. At 55° Fahr. they dissolve in 4½ times their weight of water, but require much less boiling water, from which they separate on cooling. They are soluble in alcohol.

SECTION III.

Lithium.

In the analysis of a mineral called *Petalite* (first distinguished as a new species by M. D'Andrada, who found it in the mine of Uto, in Sweden), about 3 per cent. of an alkali was obtained, which M. Arfwedson at first supposed to be soda. On more accurate examination, however, the new substance displayed properties entirely distinct from those of either soda or potassa, especially in possessing the power of neutralizing a much greater quantity of the different acids than either of those alkalies; in which respect it even surpassed magnesia. To distinguish it from the two other fixed alkalies, both of vegetable origin, it received the name of *lithion* (from λιθειος, *lapideus*); and this term, to suit the analogy of the other alkalies, was afterwards converted into *lithia* or *lithina*.

The proportion of lithia in petalite has since been found to be 5 per cent.; and, from some very pure pieces of that mineral, Vauquelin has extracted even 7 per cent. M. Arfwedson has discovered it, to the amount of 8 per cent., in *triphane* or *spodumene*, a mineral which is not so scarce as petalite; and to the extent of 4 per cent. in *crystallized lepidolite*. Dr. Turner has found it in certain varieties of mica, which he therefore calls *lithion-micas*, and Berzelius in some mineral waters. The simplest process for obtaining it consists in fusing the mineral, finely pulverized, with three times its weight of carbonate of potassa; dissolving the fused mass in muriatic acid; evaporating to dryness; and digesting in alcohol, which takes up scarcely any thing but a compound of the new earth with muriatic acid. By evaporating a second time to dryness, and again dissolving in alcohol, the muriate of lithia is obtained pure. This muriate may be decomposed by digestion with carbonate of silver; and the solution of the carbonate, being decomposed by lime or by baryta, yields a solution of pure lithia, which may be evaporated to dryness out of contact with the air, from which it rapidly imbibes carbonic acid. Berzelius finds that the most economical way of preparing lithia is to mix powdered spodumene with twice its weight of pulverized fluor spar, and with sulphuric acid; then to heat the mixture until the fluoric acid with the silica is volatilized, and afterwards to separate the sulphate of lithia by solution.

M. Arfwedson decomposed petalite by the following method. He strongly calcined, for an hour and a half, the finely powdered mineral with four times its weight of pure carbonate of baryta; digested the product with an excess of muriatic acid, which, leaving the silica undissolved, took up the baryta, alumina, &c.; precipitated the baryta by sulphuric acid, and the alumina by carbonate of ammonia; and then, evaporating to dryness the residuary liquor, and raising the heat so as to expel the ammoniacal salts, a saline residue was left, which was dissolved by water, with the exception of a small quantity of sulphate of lime. It was a neutral salt, consisting of the new substance in combination with sulphuric acid. The sulphate was decomposed by acetate of baryta, and the acetate of lithia, thus obtained, was converted by calcination into carbonate of lithia. (Ann. de Chim. et de Phys. x. 86.) For carbonate of baryta, Vauquelin and Gmelin (Ann. of Philos. xv. 341) advantageously substituted the nitrate.

Pure lithia is very soluble in water, and, like the other alkalies, has an acrid, caustic taste. Like them, also, it changes vegetable blue colours to green. When heated in contact with platinum, it fuses, and then acts on the metal. That it agrees with the other alkalies in containing a metallic base, has been proved by Sir H. Davy, who applied the power of a galvanic battery to a portion of the carbonate, fused in a platinum capsule. On rendering the platinum positive, and bringing a negative wire to the surface of the fused carbonate, the alkali was decomposed with bright scintillations: but the reduced metal burned again so rapidly, that it was only observed to be of a white colour, and very similar to sodium. Gmelin was not more successful in attempting to obtain the base of lithia separate; for as fast as it was formed it was again converted into an oxide. From analogy, this base has received the name of *lithium*. The proportion, in which this metal unites with oxygen, has, of course, not been determined by direct experiment; but it has been deduced by Vauquelin, from an analysis of the sulphate of lithia, and the application of the law, that the proportion between the oxygen of sulphuric acid and that of the bases which it saturates is as 3 to 1, to be as follows:

Lithium - -	56.50 - -	100 - -	130
Oxygen - -	43.50 - -	77 - -	100
	100.		

Arfwedson's estimate scarcely differs from this; but Gmelin deduces the composition of lithia to be 58.05 metal + 41.95 oxygen. On the whole, we may consider the atomic weight of lithium to be represented by 10, and that of lithia by 10 + 8 = 18.

Chloride of lithium may be obtained by evaporating the muriate of lithia to dryness, and fusing the residue. It is white and semi-transparent, extremely deliquescent, soluble in alcohol, is decomposed when strongly heated in the open air, when it parts with chlorine, absorbs oxygen, and becomes highly alkaline. It is very difficultly crystallizable, and tinges the flame of alcohol red. In all these respects, it presents striking differences from potassa and soda.

With *sulphur*, lithia affords a very soluble yellow compound, which is decomposed by acids, with the same phenomena as the alkaline sulphurets; and, from the abundance of the precipitate, appears to contain a large proportion of sulphur.

Sulphate of lithia crystallizes in small prisms of a shining white colour. It is more fusible and soluble than sulphate of potassa, and has a saline, not a bitter, taste. It is constituted of

Sulphuric acid - - -	59.7	or 1 atom = 40
Lithia - - - - - - -	26.9	or 1 atom = 18
Water - - - - - - -	13.4	or 1 atom = 9
	100.	Atomic weight 67

Bi-sulphate of lithia is produced by adding an excess of sulphuric acid to the neutral sulphate. It is more fusible and less soluble in water than the sulphate.

Nitrate of lithia is very soluble, and by evaporation crystallizes sometimes in regular rhomboids, sometimes in needles. It is extremely fusible; and at the instant when it has cooled, it attracts moisture from the air, and becomes fluid. The *muriate* is not crystallizable, but a crust appears on the surface of its solution during evaporation.

Carbonate of lithia is efflorescent in the air, and is sparingly soluble, requiring about 100 times its weight of cold water. It consists of 54.46 acid + 45.54. The watery solution effervesces with acids; changes vegetable blue colours to green; decomposes solutions of alumine and magnesia, and of the metals; is rendered caustic by lime; disengages ammonia from its combinations; and does not precipitate the chloride of platinum. The dry carbonate, when fused on platinum, acts as powerfully on that metal as the alkaline nitrates.

Phosphate of lithia is formed by adding phosphate of ammonia with excess of base to sulphate of lithia, when an insoluble phosphate of lithia falls down. By this property it may be separated from potassa and soda. There exists also a *bi-phosphate of lithia*.

Lithia, then, is sufficiently distinguishable both from potassa and soda, by the difficult solubility of its carbonate in water; by affording deliquescent salts with muriatic and nitric acids; and, still more, by its higher capacity of saturation. It agrees with soda in not being precipitated by tartaric acid or chloride of platinum; but the salts of lithia, when their concentrated solutions are mixed with one of carbonate of soda, deposit carbonate of lithia. Dr. Turner has discovered that it may be detected in fusible minerals by the redness which it communicates to the flame of a candle urged by the blow-pipe, and in such as are difficultly fusible by adding to them a proper flux. (Ann. of Phil. 2d Ser. xi. 131.)

SECTION IV.

Calcium.

To obtain calcium, a paste may be moulded, either of pure lime, or of sulphate of lime and water, into the shape of a small capsule, which may be placed on a metallic dish. Into this capsule mercury may be poured, and connected with the negative extremity of a galvanic apparatus of sufficient power, while the positive wire of the same pile is made to touch the under surface of the metallic plate. When the contact has been continued sufficiently long, an amalgam of mercury and calcium is obtained, which may be put into a small retort along with naphtha enough to cover it. The retort is then to be connected with a tubulated receiver, the tubulure of which is only loosely stopped with a cork. On applying heat, the naphtha first comes over; then the mercury; and the calcium remains, surrounded by an atmosphere of vapour of naphtha. As the vessels cool, it would be desirable, and would not be difficult, to fill them with nitrogen gas, to prevent the oxidation of the calcium.

At present our knowledge of calcium in a pure state is very imperfect. In the instance in which Sir H. Davy succeeded to the greatest extent in distilling the quicksilver from the amalgam, the tube unfortunately broke while warm; and at the moment when the air entered, the metal, which had the colour and lustre of silver, took fire, and burned with an intense white light into lime. Berzelius obtained an amalgam of mercury and calcium, by electrifying lime liquor in contact with mercury, and on this amalgam water was made to act. From the quantity of lime thus produced, he estimates its composition to be

Calcium	71.73	100.
Oxygen	28.27	39.4
	100.	

And 39.4 : 100 : : 8 : 20.3, which last number is the equivalent of calcium as thus deduced. Inferred by less direct methods it turns out to be exactly 20; and 20 + 8 = 28 may be regarded as representing very nearly the atom of lime.

Lime.

The external characters of lime may be exhibited in common quicklime, such as is employed for the purposes of building or agriculture. In the same state, it is generally pure enough for demonstrating its chemical properties; but, when used for purposes of the latter kind, it should be fresh burnt from the kiln. For accurate experiments, it should be prepared by calcining in a crucible for several hours, Carrara or Parian marble, or carbonate of lime which has been precipitated by carbonate of ammonia from the muriate, and perfectly edulcorated by abundance of distilled water. Its specific gravity is 2.3. It requires for its fusion the intense heat of Voltaic electricity, or of the oxy-hydrogen blow-pipe. It is not volatile.

Relation of Lime to Water.

(*a*) Lime absorbs water very rapidly, and with considerable heat and noise. By sprinkling a little water on some dry quicklime, the lime will become extremely hot, and fall into powder, which has been called *dry hydrate of lime.* In this compound, the lime is to the water, according to Mr. Dalton, as 23 to 8; according to Davy, as 55 to 17; and to Berzelius, as 100 to 32.1; which last numbers, being as nearly as possible in the proportion of the weights of the atoms of lime and water (*viz.*, 28 to 9), are probably the correct ones. It is, therefore, strictly a *proto-hydrate.* Some care is necessary in its preparation, lest more water should be added than is essential to its constitution. It affords a very convenient form of keeping lime, for occasional use in a laboratory; for the hydrate may safely be preserved in glass bottles, which are almost constantly broken by the earth, if enclosed in its perfectly dry state. The hydrate of lime differs from those of baryta and strontia, in retaining its water much less forcibly; for the whole of it may be expelled by a strong red heat; and pure and absolutely dry lime remains.

The degree of heat, produced by the combination of lime with water, is supposed by Mr. Dalton to be not less than 800°, and is sufficient to set fire to some inflammable bodies; and when a large quantity of lime is suddenly slaked in a dark place, even light, according to Pelletier, is sometimes evolved. The caloric, which is thus set at liberty, is doubtless that contained in the water, and essential to its fluidity. By combination with lime, water passes to a solid state, and probably even to a state of much greater solidity than that of ice. Hence, during this change, it evolves more caloric than during conversion into ice; and hence even ice itself, when mixed with quicklime, in the proportion of one to two, enters into a combination which has its temperature raised to 212°. When a sufficient quantity of water has been added to reduce lime into a thin liquid, this is called *milk* or *cream of lime;* but this can scarcely be regarded as a definite compound.

Lime, though not of itself volatile, is, in some manner, perhaps mechanically, carried up by the vapour of water employed in slaking it. When a piece of moistened paper, stained with the juice of the violet, is held in the steam, which arises from lime suddenly slaked, its colour is changed from blue to green. Hence the smell which is perceived during the slaking of lime.

(*b*) Lime absorbs moisture from the atmosphere, and falls gradually into powder, containing pure lime and water, in the proportion nearly of 100 to 32; or it becomes a true proto-hydrate.

(*c*) Lime is very sparingly soluble in water, *viz.*, in the proportion of about 1 to 700; according to Thomson, 1 to 758; to Davy, 1 to 450; and to Dalton, at 60° Fahr., 1 to 778. From a wine pint of lime-water prepared at 60° Fahr., Mr. R. Phillips precipitated by carbonate of ammonia 17.3 grains of carbonate, equivalent to 9.7 of lime. And as a wine pint of this lime-water weighs about 7300 grains, it follows that water at 60° Fahr. takes up about 1-752d of its weight of that earth. The experiments of Mr. Dalton tend to establish a curious fact respecting the solubility of lime, *viz.*, that it dissolves more plentifully in cold than in hot water. He has given the following table, the first column of which expresses the temperature of the water; the second, the number of grains of water, required to take up one grain of lime; and the third, the number required to dissolve one grain of hydrate of lime.

Temperature.	Grains of water that dissolve 1 gr. of lime.	Grains of water that dissolve 1 gr. of hydrate.
60°	778	584
130°	972	720
212°	1270	952

At the freezing point, or nearly so, Mr. Dalton thinks it probable that water would take up nearly twice as much lime as is dissolved by boiling water. This inference has been confirmed by Mr. R. Phillips, who, after satisfying himself of the correctness of Mr. Dalton's statement of the composition of lime-water prepared at

212°, determined by experiment that water at or near 32° Fahr. dissolves 1-656th of its weight of lime, or as nearly double as possible. He found also that the solution prepared at this temperature, when heated to ebullition in a glass vessel, from which a long tube issued to allow the escape of steam, and to prevent the access of carbonic acid, deposited small white particles of lime. These separated in such quantity, that though only 1-13th of the solution was evaporated, the proportion of lime was reduced to $\frac{1}{3000}$. The cause of this crystallization Mr. Phillips supposes to be the influence of heat in increasing the aggregate attraction of the lime; but it is probable that the heat may also operate in diminishing the affinity of water for lime. (See Ann. of Phil. N. S. i. 107.)

The watery solution of lime has an acrid disagreeable taste, turns vegetable blues to green, and unites with oil, forming an imperfect soap. To prepare the solution, lime is to be slaked to a thin paste, and a sufficient quantity of water afterwards added. The mixture is to be stirred repeatedly, the lime allowed to settle, and the clear liquor decanted for use. It must be preserved in closely stopped vessels, for reasons which have been stated in the chapter on carbonic acid.

(*d*) When lime-water is freely exposed to the atmosphere, the lime is precipitated from it in the state of a carbonate; and it is, therefore, not possible to obtain crystals of pure lime, by evaporating lime-water in the common way. Its crystallization, however, has been effected by Gay Lussac, by enclosing a vessel of lime-water, and another of concentrated sulphuric acid, under the same glass receiver. The evaporation of the water goes on quickly, especially when the sulphuric acid is occasionally renewed, and small transparent crystals are obtained in regular hexahedrons, cut perpendicularly to their axes. They remain transparent when exposed to the air for a few days, and are then changed into carbonate of lime. By ignition in a glass tube, their water of crystallization is expelled, and they are proved to consist of

Lime - -	76.26 - -	100.
Water - -	23.74 - -	31.14
	100.	

These crystals agree, therefore, very nearly in composition with the proto-hydrate, which is obtained by exposing quicklime to a damp atmosphere. This, if the atom of water be taken at 9, and the atom of lime at 28, will make that of the crystallized hydrate 37. (Ann. de Ch. et de Ph. i. 334.)

Peroxide of Calcium.

When oxygen gas is passed over ignited quicklime, the gas is absorbed, and a peroxide of calcium is obtained; the exact composition of which has not been determined. A similar peroxide, united with water, is formed also, according to Thenard, when lime is brought into contact with the deutoxide of hydrogen, discovered by that chemist.

Chloride of Calcium and Muriate of Lime.

When lime is heated in chlorine gas, 1 volume of chlorine is absorbed, and half a volume of oxygen is evolved; and a chloride of calcium is formed. The same compound is obtained by saturating muriatic acid with carbonate of lime, evaporating to dryness, and fusing the residue. In this case the muriatic acid is decomposed; its hydrogen, uniting with the oxygen of the lime, escapes in the state of water; and the chlorine unites with the calcium. The chloride and the muriate are, therefore, mutually convertible by adding or expelling water. One hundred grains of carbonate of lime afford, according to Berzelius, 109.6 of fused chloride of calcium, containing, as appears from calculation, 69.6 chlorine, and 40 of the metal, which numbers are as nearly as possible in the proportion of 36 to 20, the equivalents of chlorine and calcium. Hence the representative number of chloride of calcium is $36 + 20 = 56$; or it consists of

Chlorine - - - - - - - - - -	64
Calcium - - - - - - - - - - -	36
	100

When chloride of calcium is exposed to the atmosphere, it deliquiates very rapidly. It is of course, therefore, soluble in a very small quantity of water, and it forms a solution of a thick oily consistence, and of a bitter acrid taste. This solution, which is strictly muriate of lime, deposits crystals, if exposed to the temperature of 32° Fahr. These crystals, when mixed with fresh fallen snow, produce a degree of cold sufficient to freeze quicksilver, as already stated in the chapter on caloric. They contain, according to Dr. Thomson,

Muriatic acid -	31.09	or 1 atom	37
Lime - - -	23.53	or 1 atom	28
Water - - -	45.38	or 6 atoms	54
		Weight of its atom,	119

When the crystals are exposed to a heat gradually raised to redness, they sustain a greater loss than should arise from that of six atoms of water, for the oxygen of the lime, uniting with the hydrogen of the muriatic acid, forms an atom of water. We have therefore, from 119 parts of the salt, a loss of 54 parts $+ 9 = 63$.

Iodide of calcium is obtained by evaporating to dryness the hydriodate of lime, and strongly heating the residue. It is a white fusible compound.

Sulphuret of calcium was formed by Berzelius by passing sulphureted hydrogen gas over red-hot lime, the oxygen of which united with the hydrogen to form water, while the sulphur united with the calcium. Berthier formed it, also, by exposing anhydrous sulphate of lime to a strong heat in a charcoal crucible. In both cases a sulphuret of calcium was formed, completely soluble in water, and constituted of

Calcium -	59.09	or 1 atom =	28
Sulphur - -	40.91	or 1 atom =	16
	100.		40

Phosphuret of calcium.—There can be little doubt that this substance, though hitherto considered a compound of phosphorus with lime, is either entirely or partly a phosphuret of its metallic base, but at present we are not acquainted with its exact composition. (See Dumas, Ann. de Ch. et de Ph. xxxiii. 363.) It may be prepared as follows:

Take a glass tube, about 12 inches long, and one-third of an inch diameter, sealed hermetically at one end. Let this tube be coated with clay, except within about half an inch of the sealed end. Put first into it a drachm or two of phosphorus, cut into small pieces, and then fill the tube with small bits of fresh burnt lime, of the size of split peas. Stop the mouth of the tube loosely with a little paper, in order to prevent the free access of air.—Next, heat to redness that part of the tube which is coated with clay, by means of a chafing-dish of red-hot charcoal; and, when the lime may be supposed to be ignited, apply heat to the part containing the phosphorus, so as to sublime it, and to bring the vapour of it into contact with the heated lime. The phosphorus will decompose the lime, and will form, with the calcium, a compound of a reddish brown colour. Some useful directions for the successful performance of this process may be found in Mr. Faraday's work on Chemical Manipulation, sect. 688.

The phosphuret of lime has the remarkable property of decomposing water at the common temperature of the atmosphere; and the water afterwards contains phosphite, or hypo-phosphite, and not phosphate of lime. (Gay Lussac, 85 Ann. de Ch. 206, and Ann. de Ch. et Phys. vi. 328.) If a small piece of it be dropped into a wine-glass of water, in a short time bubbles of phosphureted hydrogen gas will be produced, which, rising to the surface, will take fire, and explode. If the phosphuret of lime be not perfectly fresh, it may be proper to warm the water to which it is added. (See chap. viii. sect. 3.)

Into an ale-glass put one part of phosphuret of lime in pieces about the size of a pea (not in powder), and add to it half a part of chlorate of potassa. Fill the glass with water, and put into it a funnel, with a long pipe, or narrow glass tube, reaching to the bottom. Through this pour three or four parts of strong sulphuric acid, which will decompose the chlorate; and, the phosphuret also decomposing the water at the same time, flashes of fire dart from the surface of the fluid, and the bottom of the vessel is illuminated by a beautiful green light. (Davy.)

Salts, &c., with Base of Lime.

Chloride of lime.—When chlorine gas is brouhgt into contact with proto-hydrate of lime, which has been passed through a fine sieve, the gas is absorbed with rapidity, and with the evolution of much heat. It is necessary, indeed, either to pass the current of gas very slowly, or to surround the vessel containing the lime with cold water; for the heat evolved is sufficient to depreciate the value of the product one-third. Occasionally, also, the surface of the lime must be changed by stirring, and, if the chloride be required of the greatest possible strength, the water, lost by evaporation during the process, must be occasionally supplied. A little excess of water does no harm, but a deficiency causes the lime to be redundant, even as much as 25 per cent. (Morin.) When the hydrate has taken all the gas that it is capable of absorbing, there remains a dry white powder, of considerable importance, from its extensive use in the art of bleaching, and known in commerce by the names of *bleaching powder*, or *oxymuriate of lime.*

This substance, called also *sub-chloride of lime*, or *sub-chloride of hydrated lime*, and by Dr. Thomson *dichloride of lime*, has a faint odour of chlorine, and a penetrating taste. When agitated with water, a portion is dissolved, varying in different specimens. The solution of a sample of fair commercial quality, when a wine gallon of water had been made to act upon a pound of the salt, I found had the specific gravity of 1.035. A large residue of undissolved matter is always left, which consists for the most part of hydrate of lime, not entirely free, however, from chlorine, the smell of which is evolved from it on adding an acid; but this, Morin found, does not exceed $\frac{1}{77}$th the chlorine originally present in a given quantity of chloride of lime. The solution in water always contains an excess of lime, and does not actively discharge vegetable colours, till some acid is added to disengage the lime from the chlorine. The disinfecting power of chloride of lime, when its solution is sprinkled in the apartments of persons labouring under fevers and other infectious diseases, is noticed in the Quart. Journ. N. S. i. 211.

Chloride of lime exposed to heat is decomposed; a small portion of chlorine gas and some water first come over; and, on raising the heat to upwards of 600°, oxygen gas is evolved, by the action of the chlorine upon the calcium, which is the base of the lime. The quicker the application of heat, the less is the proportion of chlorine liberated, and the greater that of oxygen gas. For every 50 cubic inches of oxygen that are obtained, we may reckon that 100 cubic inches of chlorine (=76¼ grains) have united with calcium. The chloride of lime is thus converted by heat into chloride of calcium. A similar change appears to take place by long keeping at ordinary temperatures; for the salt gradually loses its bleaching power. When fresh prepared, it does not essentially contain any chloride of calcium, or muriate of lime; but in a specimen which had been kept about five years, Mr. Dalton found 30 per cent. of that salt, the chloride of lime being proportionally diminished. To this change the presence of moisture, either originally contained in the salt, or acquired from the atmosphere, mainly contributes, and is probably even essential. The absorption of carbonic acid appears to perform only a secondary part.

The composition of sub-chloride of lime was first attentively examined by Mr. Dalton. (Ann. of Phil. i. 15, and ii. 6.) A specimen formed by exposing the proto-hydrate of lime to chlorine gas, till it would absorb no more, he found to be constituted of

Chlorine	23
Lime	38
Water	39
	100

These numbers do not exactly agree with any atomic proportions; but, if altered a little, as follows, to correct defects in the analysis, which are within the limits of possible error, the constitution of the salt would cease to be anomalous; *viz.*,

Chlorine	24.36	= 1 atom	36
Lime	38.54	= 2 atoms	56
Water	37.10	= 6 atoms	54
	100.		146

Each atom of lime appears, therefore, to have been united with 3 atoms of water, or to have been in the state of tri-hidrate. These proportions of chlorine and lime are such as to constitute a true *sub-chloride*, as Mr. Dalton names it; or *sub-bichloride* or *dichloride*, as it has been called by Dr. Thomson.

When water was made to act upon the sub-chloride, Mr. Dalton found that one-half of the whole lime was deposited; a boiling heat was also found by him to disengage oxygen gas from it in abundance, and not more than 1-300th of the chloride escaped decomposition. In the remaining liquid, analyzed by adding carbonate of potassa, he found that there were present 1 atom of chlorate of lime, and 16 atoms of chloride of calcium. Of the evolved oxygen, each volume, according to Morin, represents two-thirds of the chlorine present in the decomposed portion of chloride of lime. The atom of chlorine, therefore, is, in the solution, engaged by an atom of base, constituting a true *chloride of lime*. This compound is probably not capable of existing long in solution. When exposed to the air, it soon becomes covered with a pellicle of carbonate of lime, and when this is broken, with another; and this goes on in succession. But, besides this displacement of chlorine by the carbonic acid of the atmosphere, Morin observed a spontaneous decomposition going on beneath the superficial pellicle, and a discharge of oxygen gas, accompanied with a diminution of bleaching power in the liquid, even when guarded from the action of light; and this continued till the chloride was entirely decomposed.

In their views of the constitution of chloride of lime, Dr. Thomson (Ann. of Phil. xv. 401), M. Welter (Ann. de Ch. et de Phys. vii. 383), and M. Morin (Ann. de Ch. et de Ph. xxxvii. 140), for the most part agree; except that they assign, to the dry salt, proportions of water differing from those of Mr. Dalton. They admit that a partition of the base is effected by solution, and that, in the liquid, the existing compound contains an atom of each of its elements.

The assay of sub-chloride of lime, in order to ascertain its commercial value, has been effected in several ways. Mr. Dalton first proposed detaching the gas from a given weight either of the dry or liquid compound, over mercury in a graduated tube, by means of an acid. A portion of the chlorine is retained by the liquid, which may be estimated at twice its volume; but no sensible error is, it seems, occasioned by the action of the chlorine on the mercury. He afterwards announced what he considers as an improved method, *viz.*, the successive addition of a solution of the chloride to a solution of green sulphate of iron (sp. gr. 1.149) till the smell of chlorine is developed. This method, however, I consider as greatly inferior to that of liberating the chlorine by an acid. To effect this, without the aid of a mercurial trough, Dr. Ure has contrived an instrument described in the Quarterly Journal, xiii. 21. For the purposes of the artist, I believe, however, the most practicable method will be found to be the test of solution of indigo in sulphuric acid. It may be of such strength, that 1600 parts of the liquor contain 1 of indigo. Of this solution, 100 cubic inches of chlorine = 76¼ grains, destroy the colour of 1159.5 cubic inches, or 10 grains of chlorine discharge the colour of 152 cubic inches of the solution. It is desirable to dilute the solution of chloride of lime, so that its volume may be nearly one-half that of the colour test; to pour the former into the latter slowly and at intervals, stirring the mixture well after each addition; and, in making several comparative experiments, to take care that the quality of the test, and the manner of proceeding, shall be precisely the same in all. M. Gay Lussac has contributed to render the assay of chloride of lime by indigo more certain and correct, by the invention of an apparatus for the purpose, which he calls a *chlorometer*, and by a minute description of all the necessary manipulations. (Ann. of Phil. viii. 218.) The careful observance of these directions will doubtless obviate many sources of error; but the variable quality of indigo must prevent every method of employing that substance from being an universal and infallible test of the strength of chloride of lime; and when a precise analysis is required, the actual measurement of the disengaged chlorine is alone to be depended upon.

Morin has lately recommended a solution of muriate of manganese, as a more certain measure of the quantity of chlorine in chloride of lime. When the solutions are mixed, the lime seizes the muriatic acid, some chlorine escapes, and the brown oxide of manganese is precipitated. The solution of manganese being of known strength, indicates the quantity of the chloride decomposed by it; and affords, according to Morin, an uniform test, which is not decomposed like solution of indigo in sulphuric acid, when kept any moderate time.

Chlorate of lime may be formed by acting on carbonate of lime with chloric acid. A deliquescent compound is obtained, of a sharp and bitter taste, soluble in alcohol, and giving oxygen gas when heated. It is constituted, according to Chevenix, of 55.2 acid + 28.3 lime + 16.5 water.

Iodate of lime requires for solution several hundred times its weight of water. When exposed to a strong heat, it is decomposed, oxygen and iodine are given off, and the base remains.

Hydriodate of lime is deliquescent, crystallizable, enters into fusion at a heat a little below redness, and is converted into iodide of calcium in close vessels; but when heated with the free access of air, much of the iodine is separated, and a sub-iodide of calcium remains.

Nitrate of Lime.

This salt is found abundantly in the cement of old buildings, which have been long inhabited. To prepare it artificially, nitric acid, diluted with five or six parts of water, may be saturated with carbonate of lime, 63 parts of which are decomposed by 90.25 of nitric acid of density 1.5, and give 103.05 of dry nitrate of lime. (Phillips, Journal of Science, v. 167.) When the solution is boiled down to the consistence of syrup, and exposed in a cool place, long prismatic crystals are formed, resembling, in their disposition, bundles of needles diverging from a common centre. These crystals are readily soluble in water, of which, at 60°, they require two parts, and boiling water dissolves an equal weight. They deliquiate speedily, when exposed to the air; and are decomposed at the temperature of ignition. Exclusive of water, this salt contains,

	Acid.	Base.
According to Dalton - - - -	61.3	38.7
———— Phillips - - - -	65.6	34.4

The latter numbers agree very nearly with its atomic constitution, *viz.*,

Nitric acid - - -	65.86 or 1 atom	= 54
Lime - - - - -	34.14 or 1 atom	= 28
	100.	82

When a solution of nitrate of lime is evaporated to dryness in an earthen vessel, then fused for five or ten minutes in a crucible, and poured, while in fusion, into an iron pot previously heated, the congealed mass forms *Baldwin's phosphorus*. It must be broken into pieces, and preserved in a well-stopped phial. These pieces, after having been exposed to the sun for a few hours, emit in the dark a beautiful white light, affording one variety of solar phosphorus.

Carbonate of Lime.

Lime has a strong attraction for *carbonic acid*, but not when perfectly dry; for if a piece of dry quicklime be passed into a jar of carbonic acid gas over mercury, no absorption whatever ensues. But if a bottle, filled with carbonic acid gas, be inverted over a mixture of lime and water of the consistence of cream, a rapid absorption will be observed, especially if the bottle be agitated; or if a jar or bottle, filled with carbonic acid, be brought over a vessel of transparent lime-water, on agitating the vessel, a rapid diminution will ensue, and the lime-water will become milky. When a shallow vessel of lime-water is exposed to the air, a white crust forms on the surface, and this, if broken, falls to the bottom, and is succeeded by another, till the whole of the lime is precipitated from the solution. This is owing to the absorption of carbonic acid gas from the air by the lime, which is thus rendered insoluble in water. Dry lime, also, when exposed to the atmosphere, first acquires moisture, and, having become a hydrate, next absorbs carbonic acid. In a sufficient space of time, all the characters distinguishing it as lime disappear, and it acquires the property of effervescing with acids. The strong affinity of lime for carbonic acid enables it to take this acid from other substances. Thus carbonates of alkalies are decomposed by lime. Slake a given quantity of lime into a paste with water, and add half its weight of carbonate of potassa or soda. Boil the mixture, for half an hour, in an iron kettle, and separate the liquid part by filtration or by subsidence. The carbonic acid combines with the lime, and the alkali is obtained in a state of solution perfectly free from carbonic acid. This is the ordinary mode of depriving the alkalies of carbonic acid.

Carbonate of lime is a most abundant product of nature. In the forms of lime-stone, marble, and chalk, it constitutes extensive strata, and it is the basis also of calcareous spar and stalactites. Carrara marble of perfect whiteness, or transparent and colourless calcareous spar, are its purest forms; but, for common purposes, chalk may be employed to exhibit its properties.

The carbonic acid existing in carbonate of lime is expelled by a strong red heat. If distilled in an earthen retort, carbonic acid gas is obtained, and lime remains in the retort in a pure or caustic state. By this process perfectly dry carbonate of lime loses 44 per cent.

The experiments of Sir James Hall have proved, that when the escape of the carbonic acid is prevented by strong pressure, carbonate of lime is fusible at a heat of about 22° of Wedgwood's pyrometer. (Nicholson's Journal, xiii. xiv.) And Mr. Bucholz has fused this substance, by the sudden application of a violent heat, without additional compression. (Ibid. xvii. 229.)

Carbonate of lime is decomposed by almost all acids. This will appear, if upon chalk or marble, contained in a gas bottle, diluted sulphuric or muriatic acid be poured. A violent effervescence will ensue, owing to the escape of carbonic acid gas, which may be collected over water or mercury. By a little modification of the experiment, the quantity of carbonic acid expelled from the carbonate may be correctly ascertained. Let 100 grains of the carbonate be put into a Florence flask, with an ounce or two of water; place this in the scale of a balance; and in the same scale place another bottle, containing about half an ounce of muriatic acid. Add the muriatic acid to the carbonate as long as any effervescence is produced, and then blow out that part of the disengaged carbonic acid, which remains in the flask, by a pair of bellows. Ascertain, by adding weights to the opposite scale, how much has been lost; suppose it to be 43.5 grains; this shows the quantity of carbonic acid disengaged. Calcine another 100 grains in a covered crucible. It will lose rather more weight; because, besides carbonic acid, all the water is expelled which it may contain. Let this loss be stated at 45 grains; the former loss deduced from this (45 — 43.5), or 1.5 grain, shows the quantity of water in 100 of the carbonate. The proportion, however, thus discovered, is so small that it may be considered as an accidental ingredient. Independently of water, it is constituted,

	Acid.	Base.
According to Dr. Wollaston, of - -	43.7	56.3
———— Berzelius, of - - - -	43.6	56.4

Its true composition is probably,

Carbonic acid - - - 44 or 1 atom = 22
Lime - - - - - - - 56 or 1 atom = 28
100 Atomic wt. 50

Carbonate of lime, though scarcely dissolved by pure water, is soluble in water saturated with carbonic acid. The most striking method of showing this is the following: Add to a jar, about one-fourth filled with lime-water, a very small quantity of water saturated with carbonic acid. An immediate milkiness will ensue, because the carbonic acid forms with the lime an insoluble carbonate. Add gradually more and more of the water, impregnated with carbonic acid, shaking the vessel as these additions are made. At last the precipitate will be completely re-dissolved. Hence it appears that lime, united with a certain proportion of carbonic acid, is insoluble, and, with a still larger, again becomes soluble in water. By heating the solution of lime in carbonic acid, we do not, as in the case of alkaline solutions, obtain a bi-carbonate of lime, which is a salt still unknown; but the lime is thrown down in the state of simple carbonate, and the excess of carbonic acid escapes into the atmosphere.

Carbonate of lime is decomposed into its ultimate elements by being heated with phosphorus, as was discovered by the late Mr. Smithson Tennant. The process resembles that already described for making phosphuret of calcium, except that powdered marble is to be substituted for the pure earth. The experiment succeeds best if the marble is slightly calcined. When the tube has remained red-hot for some minutes, it may be taken from the fire, and must be suffered to grow cold before it is broken. It will be found to contain a black powder, consisting of charcoal mixed with phosphuret of calcium and phosphate of lime. The lime and phosphoric acid may be separated by solution in an acid, and by filtration, and the phosphorus by sublimation. (Phil. Trans. 1791.) This beautiful experiment furnished decisive evidence of the nature of carbonic acid, before we were fully in possession of the synthetic proofs by which its composition is now established.

Borate of lime may be formed by adding a solution of boracic acid to lime-water. The resulting compound is a white tasteless powder, which dissolves very sparingly in water.

Fluate of lime.—There is a natural product well known in Derbyshire, and other parts of the world, under the name of *fluor spar*, which is worked into a variety of ornaments. It most commonly, when crystallized, occurs in cubes, but its primitive form is an octahedron. Its specific gravity is 3.15. It is perfectly tasteless, and insoluble in water. When thrown in powder upon a plate of iron heated below redness, in a dark place, it emits a phosphorescent light. Concentrated sulphuric acid occasions an effervescence by expelling fluoric acid gas.

Fluate of lime contains	Fluor Acid.	Lime.
According to Davy - - - - - - -	27.859 - -	72.141
———— Berzelius (1824) - -	27.3145 - -	72.6855
———— Thomson - - - - -	26.3158 - -	73.6842

The last numbers are derived from experiment, corrected so as to correspond with the notion that fluate of lime consists of 1 atom of acid + 1 atom of base. The view of its composition, which makes it consist of an atom of fluorine + an atom of calcium, has already been stated in the article on hydro-fluoric acid. (Page 254.)

Phosphite of lime has not been particularly examined. The hypophosphite has been submitted to experiment by Rose. (Ann. de Ph. Feb. 1827. p. 430.)

Phosphate of lime derives importance from its being the principal ingredient of animal bones, of which it constitutes about 86 per cent. It may be obtained by dissolving bones, which have been well calcined and then pulverized, in dilute muriatic acid, and precipitating the solution with pure ammonia. The precipitate, when sufficiently edulcorated, is *phosphate of lime.* It is an insipid white powder, insoluble in water, but soluble in diluted nitric, muriatic, and acetic acids, and again precipitable, unaltered, from those acids, by caustic ammonia. At a high temperature, it fuses into an opaque white enamel. It is constituted, according to Mr. Dalton's experiments, of 49 acid + 51 lime, proportions so near equality, that we may consider phosphate of lime as consisting of 1 atom of acid = 28, + 1 atom of base = 28, the compound atom being 56.

Bi-phosphate of lime may be formed by digesting phosphate of lime with a quantity of phosphoric acid equivalent to that already engaged in the salt. The solution has an acid, and somewhat harsh and disagreeable taste. It does not crystallize, but forms, when evaporated, a white mass, which attracts moisture from the air. Before the blow-pipe it melts into a transparent glass, insoluble in water.

Tri-phosphate of lime.—This salt, according to Mr. Dalton, may be formed by adding pure phosphoric acid to lime-water, till a commencement of precipitation appears, when the solution must be cleared by a drop or two of acid. If the solution be evaporated to dryness at a moderate heat, and then dissolved in water again, simple phosphate of lime remains, and a quadri-phosphate exists in the solution.

Quadri-phosphate of lime.—If 100 parts of phosphate of lime be digested for 24 hours with 87 parts of sulphuric acid diluted with a sufficient quantity of water, and be then filtered, the liquid which passes through contains the whole of the phosphoric acid, with only one-fourth of the lime which existed in the original salt, the remaining ¾ths having formed an insoluble compound with the sulphuric acid. The dissolved salt is, therefore, a compound of 1 atom of lime = 28, + 4 atoms of acid = 112. When evaporated, it forms, on cooling, pearly scales, which have an acid taste, and dissolve readily in water, giving a solution of the sp. gr. 1.44. When dried and fused in a crucible, a transparent glass is obtained, commonly called *glacial phosphoric acid*, and employed chiefly in the production of phosphorus.

Octo-phosphate of lime.—Mr. Dalton is of opinion that a compound of 8 atoms of acid and 1 atom of lime is the true result of the process described under the last head; and that a compound of as many as 12 atoms of acid with one of lime may exist, forming a *dodecaphosphate*.

Hydro-sulphuret of lime is obtained by transmitting a current of sulphureted hydrogen gas through water in which lime is kept mechanically suspended. It is crystallizable, and the crystals are colourless and readily soluble in water.

Hydrogureted sulphuret of lime is formed whenever the sulphuret of calcium is dissolved in water, or by boiling together three parts of hydrate of lime, one of sulphur, and ten of water. The compound has a deep orange colour, and derives importance from its use as an eudiometrical test. From the experiments of Vauquelin, it seems probable that it is subject to variety in its proportions, and to corresponding differences in its properties. (Ann. de Chim. et de Phys. vi. 39.)

Mr. Herschell, by boiling 3 parts of hydrate of lime with one of sulphur and 20 of water, and allowing the solution to cool over the sediment, obtained crystals, which, when dried by sulphuric acid under an exhausted receiver, had the shape of quadrilateral prisms somewhat elongated, with dihedral summits. They dissolved sparingly in cold water; the solution had the sp. gr. of 1.0105, was yellow, and had an acrid sulphurous taste. The crystals are constituted of 2 atoms of lime, 2 of sulphur, + 1 of hydrogen, (forming bi-sulphureted hydrogen,) and 4 of water. When these crystals are triturated with sulphurous acid, the smell of the acid disappears, and hypo-sulphite of lime is formed.

Hypo-sulphite of lime.—By passing a current of sulphurous acid gas through a solution of the hydrogureted sulphuret of lime, the whole of the acid gas is converted into hypo-sulphurous acid. When this solution is boiled down to a certain degree of consistence, sulphur and sulphite of lime separate abundantly. The solution, evaporated at a temperature not exceeding 130° or at most

140° Fahr., and filtered while hot, yields on cooling large and very beautiful crystals, which affect a variety of complicated forms.

These crystals are *hypo-sulphite of lime*. They are very soluble in water, which, at 37° Fahr. dissolves nearly its own weight, during which the thermometer falls to 31°. The specific gravity of the solution, saturated at 50°, is 1.300. The crystals are not altered by exposure to air of the usual humidity; but when dried by sulphuric acid *in vacuo*, or at 100° Fahr. in the air, they become covered with a white efflorescence, which destroys their lustre without altering their figure. They are insoluble in alcohol of sp. gr. 0.823, which also precipitates them from their watery solution. By an analysis very carefully and skilfully conducted, Mr. Herschell found them to be composed of

		Atoms.	
Hypo-sulphurous acid -	36.71 =	2 =	48
Lime - - - - - - -	21.71 =	1 =	28
Water - - - - - - -	41.58 =	6 =	54
	100.		130

Or they consist (exclusively of water) of two atoms of acid united with one of base, the acid being composed of oxygen and sulphur atom to atom. (Edinburgh Phil. Journ. i. 17.) In strictness, therefore, this salt is a *bin-hyposulphite*.

Sulphite of lime may be obtained by passing a current of sulphurous acid through water in which carbonate of lime is kept mechanically suspended. If the sulphurous acid be in excess, the resulting salt is soluble, and its solution, when evaporated, crystallizes on cooling in six-sided prisms, terminated by long six-sided pyramids. It is at first almost tasteless, but when kept in the mouth has a sulphurous flavour. It requires for solution about 800 parts of water. By exposure to the air, the surface of the crystals is changed into sulphate of lime, and the same conversion is rapidly effected by heating it. It is constituted of

Acid - - - - - - - - - -	54.29
Lime - - - - - - - - - -	45.71
	100.

Sulphate of Lime.

Sulphate of lime may be formed, by mixing the solutions of muriate of lime and sulphate of soda in equivalent quantities, washing the precipitate abundantly with water, and heating it to dull redness to expel the remaining water. It is also found native, in great abundance, under the names of gypsum, plaster of Paris, &c.

It has the following properties:

1. It is insipid and free from smell.
2. It is difficultly soluble, requiring 500 times its weight of cold water, or 450 of hot water.
3. It is fusible by a moderate heat. When sulphate of lime, which has been dried at 160° Fahr., is exposed to a low red heat,

100 grains lose 22 according to Berzelius, or 21 according to Bucholz, consisting entirely of water. After calcination, it absorbs water, becomes hot, and sets rapidly.

4. It is decomposed by alkaline carbonates, a double exchange of principles ensuing. Hence the milkiness which ensues on adding carbonate of potassa to many spring waters; the carbonate of lime, which is generated, being less soluble than the sulphate. Hence, also, hard waters, which mostly contain sulphate of lime in solution, curdle soap, the alkali of which is detached by the sulphuric acid, and the oil is set at liberty.

5. It is decomposed by ignition with charcoal, which separates the oxygen of the sulphuric acid, and leaves a combination of lime with sulphur.

By dissolving 100 grains of calcined sulphate of lime in boiling distilled water, and adding muriate of barytes, I obtained a precipitate, which, when well washed, dried, and calcined in a low red heat, weighed 175.9. Hence 100 parts of calcined sulphate of lime must contain very nearly,

	Acid.	Base.
According to the above experiment - -	59 -	41
———— Thomson and Berzelius -	58 -	42
———— Dalton - - - - - - - -	58.60 -	41.40

Its true composition appears to be

Sulphuric acid - - -	58.42 or 1 atom	= 40
Lime - - - - - - -	41.58 or 1 atom	= 28
	100.	68

Sulphate of lime is often found in a crystallized form, and then consists of

Sulphate of lime - -	79.07 or 1 atom	= 68
Water - - - - -	20.93 or 2 atoms	= 18
	100.	86

Seleniate of lime.—Selenic acid is capable of uniting with lime in two different proportions, forming a seleniate and a bi-seleniate; but these salts have no particularly interesting properties.

Ferro-cyanate of lime.—This compound, which is useful as a test of iron, may be formed by adding powdered prussian blue to lime-water, till the lime no longer alters paper stained with turmeric. If this effect be still slightly produced, a little more prussian blue may be added, and the mixture boiled a short time and filtered. The filtered liquor has a greenish yellow colour, and an unpleasant bitterish taste. Its specific gravity is 1.005. When evaporated, it yields small crystalline grains, which dissolve sparingly in water, and are insoluble in alcohol.

SECTION V.

Barium.

Barium was obtained by Sir H. Davy by distilling its amalgam, which had been formed in the following manner. A quantity of native carbonate of baryta was made into a paste with water, and placed on a tray of platinum; a cavity was made in the paste to receive a globule of mercury, which was rendered negative, at the same time that the platinum was made positive by means of a Voltaic battery, containing about 100 double plates. In a short time an amalgam was formed, consisting of mercury and barium. This amalgam was introduced into a little tube made of glass, free from lead, which was bent into the shape of a retort, then filled with the vapour of naphtha, and hermetically sealed. Heat was then applied to the tube, till all the mercury was driven off.

The residuum of this distillation was a dark grey metal, with a lustre inferior to that of cast iron. At the ordinary temperature of the air it remained a solid; but became fluid at a heat below redness. It did not rise in vapour till heated nearly to redness, and then acted violently upon the glass.

When exposed to the air, this substance rapidly tarnished, and fell into a white powder, which was baryta. When this process was conducted in a small portion of air, the oxygen was absorbed; and the nitrogen remained unaltered. A portion of it thrown into water acted upon it with great violence, and sank to the bottom, producing baryta, and evolving hydrogen gas.

The quantities obtained were too minute, for an examination either of its physical or chemical qualities. It sank rapidly in water, and even in sulphuric acid, though surrounded by globules of hydrogen equal to two or three times its volume. Hence it is probable that it cannot be less than four or five times as heavy as water. It was flattened by pressure, but required considerable force for this effect.

The proportion of the components of baryta, Sir H. Davy deduces to be 89.7 barium and 10.3 oxygen per cent. The determination of Berzelius nearly agrees with this, *viz.*,

Barium - - -	89.52 - - -	100.00
Oxygen - - -	10.48 - - -	11.69
	100.	111.69

Its true composition appears to be

Barium - -	89.744	or 1 atom	= 70
Oxygen - -	10.256	or 1 atom	= 8
	100.	Wt. of its atom	78

It is necessary, however, to state, that the exact equivalent for barium, and consequently for baryta and all its salts, is a subject of controversy. Berzelius contends for a number on his scale equivalent to 68.86 on that of the hydrogen scale, used in this country. Dr. Thomson adheres to the number (70) given in his First Principles, and the latter number I shall continue to employ until farther evidence has been produced of its incorrectness. (See Ann. of Phil. Dec. 1828, March 1829.)

Baryta may be obtained for experimental purposes from the nitrate or carbonate of that earth, in the manner which will presently be described. It exhibits, when pure, the following properties:

1. Baryta, in a pure form, has a sharp caustic taste; changes vegetable blue colours to green; and serves as the intermedium between oil and water. In these respects, it bears a strong resemblance to alkalies.

2. When exposed to the flame of the blow-pipe on charcoal, it melts; boils violently; and forms small globules, which sink into the charcoal. After being kept in fusion in a crucible during ten minutes, it still, according to Berthollet, contains 9 per cent. of water; from theory it should contain 10.59 per cent. This, however, is true only of baryta which has been obtained from the carbonate by a process to be described hereafter. Baryta, procured by decomposing the nitrate of that earth, is not fusible, and appears to contain little, if any, water. (Nich. Journ. xxiii. 281.)

3. If a small quantity of water be added to recently prepared baryta, it is absorbed with great rapidity; prodigious heat is excited; and the water is completely solidified, a sort of hard cement being obtained. A little more water converts this mass into a light bulky powder; and, when completely covered with water, the baryta is dissolved. Boiling water should be employed for this purpose; unless sufficient temperature has been produced, by the sudden addition of the whole quantity necessary for solution.

4. When the solution, prepared with boiling water, is allowed to cool slowly, it shoots into regular crystals. These have the form of flattened hexagonal prisms, having two broad sides, with two intervening narrow ones; and terminated, at each end, by a quadrangular pyramid. They lose, according to Bucholz, half their weight of water in a red heat; the baryta then continues fused, and parts with no more water, though still combined with the proportion above stated. Mr. Dalton, from his experiments, infers that the crystals contain 30 baryta and 70 water per cent., which would make them consist of 1 atom of baryta + 20 atoms of water.

5. The crystals are so soluble, as to be taken up, when heated, merely by their own water of crystallization. When exposed to a stronger heat, they swell, foam, and leave a dry white powder, amounting to about 47 parts from 100 of the crystals. This again combines with water with great heat and violence. At 60° Fahr. an ounce measure of water dissolves only 25 grains of the crystals, *i. e.*, they require for solution 17½ times their weight of water. Exposed to the atmosphere, they effloresce, and become pulverulent.

6. When added to spirit of wine, and heated in a spoon over a lamp, they communicate a yellowish colour to its flame.

7. The specific gravity of this earth, according to Fourcroy, is 4; but Hassenfratz states it at only 2.374. The former account,

however, is the more probable. All its combinations have considerable specific gravity; and hence its name is derived, *viz.*, from the Greek word βαρὺς, signifying heavy.

8. Baryta does not unite with any of the alkalies.

Peroxide of Barium.

Barium has been shown, by Gay Lussac and Thenard, to be capable of uniting with an additional atom of oxygen; for when that earth, prepared from the nitrate, was ignited in oxygen gas, the gas was rapidly absorbed, and a grey compound was formed, glazed on its outer surface. This compound may be called *deutoxide* or *peroxide* of *barium;* and it appears to be constituted of 1 atom of the metal = 70, + 2 atoms of oxygen = 16, together 86. To prepare the peroxide, Thenard recommends that the nitrate of baryta be ignited in a retort of white porcelain (one of Wedgwood's ware is well adapted to the purpose) till oxygen gas ceases to be evolved. The product, hastily broken into fragments about the size of a hazlenut, is to be put into a well-luted green glass tube, which is to be placed horizontally in a furnace, and heated to dull redness. A current of oxygen gas, dried by having first been passed over quicklime, is then to be transmitted through the tube, and continued ten or fifteen minutes. The gas is rapidly absorbed, and a greyish white substance obtained, which is the *peroxide*, the compound employed by Thenard in giving an additional proportion of oxygen to water. (See p. 237.) Quesneville, jun., finds it sufficient, in order to obtain the peroxide, to continue the distillation of the nitrate at a red heat, till nitrous and azotic gases cease to be evolved, and to withdraw the fire the moment oxygen gas begins to come over. In the retort, there remains a deutoxide of barium, possessing all the distinguishing characters of that compound. (Ann. de Ch. et de Ph. xxxv. 108.)

Chloride of Barium.—Muriate of Baryta.

Chloride of barium may be formed by heating pure baryta in chlorine gas, each volume of which disengages half a volume of oxygen gas from that earth. Or when baryta is heated in muriatic acid gas, the gas disappears, and the chloride, which is produced, becomes red-hot. But, for purposes of experiment, this salt is best prepared by dissolving either the artificial or native carbonate in muriatic acid much diluted; or, if neither of these can be had, the sulphuret. The iron and lead, which are occasionally dissolved, along with the baryta, may be separated by the addition of a small quantity of liquid ammonia, or by boiling and stirring the solution in contact with a little lime; or, which is still better, by solution of baryta in water. When filtered and evaporated, the solution, which contains muriate of baryta (not chloride of barium), yields regular crystals of the former salt, which have most commonly the shape of tables, bevelled at the edges, or of eight-sided pyramids, applied base to base. These crystals dissolve in five parts of water, at 60°, or in a still smaller quantity of boiling water; and also in alcohol. They are not altered by exposure to the atmosphere. Sulphuric acid detaches the baryta, and the salt is also decomposed by alkaline carbonates and sulphates. When the crystals are exposed to a red heat, they are converted into chloride of barium.

Chloride of barium consists of

Chlorine - - -	34	or 1 atom =	36
Barium - - -	66	or 1 atom =	70
	100	Weight of its atom	106

By solution in water it is converted into muriate of baryta, each atom decomposing 1 atom of water; hence 36 of chlorine unite with 1 of hydrogen, and 8 of oxygen with 70 of barium, and we have muriate of baryta, which, *supposed anhydrous*, consists of

Muriatic acid	32.17	or 1 atom =	37
Baryta - -	67.83	or 1 atom =	78
	100.	Weight of its atom	115

By exposing 124 grains of the hydrous crystals to a red heat, they are found to lose as nearly 18 as possible, which on first view might appear to be their water of crystallization, and to agree with 2 atoms (9 × 2). But it must be remembered, that part of this loss is owing to the conversion of the muriate into chloride. We are therefore to deduct 8 (the oxygen of the baryta) + 1 (the hydrogen of the muriatic acid) together 9, and we have then 9 for the true loss of water, existing as such in the crystallized muriate of baryta, which, under this view, consists of

Muriatic acid	29.84	or 1 atom =	37
Baryta - -	62.90	or 1 atom =	78
Water - -	7.26	or 1 atom =	9
	100.	Weight of its atom	124

Chlorate of baryta.—To prepare this salt, chlorine gas must be received into a warm solution of baryta in water, till the baryta is saturated. The solution is to be filtered, and boiled with phosphate of silver, which decomposes the common muriate of baryta only, and at the same time forms two insoluble salts, phosphate of baryta, and chloride of silver. Vauquelin finds the addition of acetic acid recommended by Chevenix objectionable, and that the compounds of chloric acid are liable, if acetic acid has been employed, to detonate violently when heated. To judge when enough of the phosphate of silver has been used, add to a portion of the filtered liquor a few drops of nitrate of silver, which, in that case, ought not to disturb its transparency. If too much phosphate of silver has been used, a drop or two of muriatic acid will discover it, and, in that case, the cautious addition must be made of some of the original solution set apart for the purpose, to which no phosphate of silver has been added. It is from solution of chlorate of baryta, thus carefully prepared, that chloric acid is obtained by the intervention of sulphuric acid, as described page 199.

Chlorate of baryta has the form of four-sided prisms; its taste is pungent and austere; it requires for solution about four times its weight of water, at 50° Fahrenheit; and its solution, when pure, is not precipitated either by nitrate of silver or muriatic acid. By a red heat, it loses 39 per cent., and the residue is alkaline. From calculation, it should consist, besides water, of

1 atom of baryta - -	78 - -	50.6
1 atom of chloric acid	76 - -	49.4
	154	100.

Iodide of barium may be formed by evaporating and igniting the hydriodate of baryta. The hydrogen of the acid unites with the oxygen of the earth, and the iodine with its metallic base.

Hydriodate of baryta is extremely soluble in water, and rather deliquescent. It crystallizes in very small prisms, which are decomposed by mere exposure to the atmosphere, into water, a salt with excess of iodine, and carbonate of baryta. When ignited in close vessels, it is converted into iodide of barium. It is constituted of 100 acid + 60.62 baryta.

Iodate of baryta is an extremely insoluble salt. It may be formed by adding iodine to solution of baryta, from which the iodate precipitates in the state of a white powder, and may be edulcorated by washing with distilled water. When strongly heated, oxygen and iodine are evolved from it, and baryta remains. It consists of 100 acid + 46.34 base.

Nitrate of Baryta.

Nitrate of baryta may be prepared by dissolving either the artificial or native carbonate in nitric acid, diluted with 8 or 10 parts of water. If the artificial carbonate be employed, it should be previously well washed with distilled water, till the washings cease to precipitate nitrate of silver. A solution of nitrate of baryta, mixed with a drop or two of nitrate of silver, should continue perfectly transparent. On evaporation, it yields crystals, the primary form of which is a regular octahedron, but commonly so much flattened in one direction, that their relation to the primary form is not very apparent. (See Mr. Brooke's representation of them, Ann. of Phil. N. S. vii. 21.) They contain no water of crystallization.

Nitrate of baryta requires for solution 12 times its weight of water at 60°, and 3 or 4 parts of boiling water. It is not altered by exposure to the air. In a red heat, its acid is decomposed, and the earth remains pure. This furnishes another method of procuring pure baryta; but the heat must not be carried too far, otherwise the baryta is apt to vitrify with the porcelain crucible or retort. The residue, on the addition of water, dissolves with great heat and noise, and the solution, on cooling, yields crystals of pure baryta.

Nitrate of baryta consists of

		Acid.		Base.
According to Clément and Desormes	-	40	-	60
——— Mr. Jas. Thomson - - -	-	40.7	-	59.3
——— Berzelius - - - - - -	-	41.54	-	58.46

If a compound of 1 atom of acid + 1 atom of base, it should consist of

Baryta - - - - - -	78 - -	58.94
Nitric acid - - -	54 - -	41.06
	132	100.

Carbonate of Baryta.

Pure baryta has a very powerful affinity for carbonic acid, as may be shown by exposing a solution of that earth in water to the atmosphere. It will soon be covered with a thin white pellicle; which, when broken, will fall to the bottom of the vessel, and be succeeded by another. This may be continued till the whole of the baryta is separated. The effect arises from the absorption of carbonic acid, which forms with baryta a compound, *viz.*, carbonate of baryta, much less soluble than the pure earth. Or if the air from the lungs be blown by means of a quill, or glass tube, through a solution of baryta, the solution will immediately become milky, in consequence of the production of an insoluble carbonate. The same effect will be produced by mingling, with a solution of pure baryta, a little water impregnated with carbonic acid. In this case, also, an immediate precipitation of carbonate of baryta will ensue.

Baryta has so strong an affinity for carbonic acid, as even to take it from other bodies. If to a solution of a small portion of carbonate of potassa, of soda, or of ammonia, we add the solution of baryta, the earth will detach the carbonic acid from the alkali, and will fall down in the state of a carbonate. By adding a sufficient quantity of a solution of baryta in hot water, the whole of the carbonic acid may thus be removed from a carbonated alkali, and the alkali will remain perfectly pure.

Carbonate of baryta has the following properties:

1. It is nearly insoluble in water, which, at 60°, does not take up more than $\frac{1}{4300}$ part, or, when boiling, about $\frac{1}{2300}$. Water impregnated with carbonic acid dissolves [illegible]th.

2. Carbonate of baryta is perfectly tasteless, and does not alter vegetable blue colours. It acts, nevertheless, as a violent poison.

3. The combination of carbonic acid with baryta may either be produced artificially, in the manner already described, and by other processes, to be detailed in the sequel, in which case it is termed the *artificial carbonate*;—or it may be procured ready formed as a natural product, and is then called the *native carbonate*. The largest quantity hitherto discovered is in a mine, now no longer worked, at

Anglezark, near Chorley, in Lancashire, but it is also found in several other places.

The following table shows the experimental results of its analysis by various chemists:

	Carb. acid.	Baryta.
Analysis of Mr. Aikin - - - -	21.67 - -	78.33
———— Mr. Jas. Thomson - -	21.75 - -	78.25
———— Klaproth and Rose - -	22.00 - -	78.00

Carbonate of baryta appears then to be constituted of 1 atom of base and 1 atom of acid. Hence it ought to consist of

Baryta - - - - -	78 - -	100
Carbonic acid - -	22 - -	28.54
	100	128.54

4. When 100 grains of the carbonate are dissolved in nitric acid, and precipitated by a sulphate, they afford, according to Berzelius, 118.6 or 119 grains of sulphate of baryta.

5. Carbonate of baryta is decomposed by an intense heat; its carbonic acid being expelled; and the baryta remaining pure. The artificial carbonate is most readily decomposed; but the native one is generally employed for obtaining pure baryta, because it may be had at considerably less expense. The process, which I have found to answer best, is nearly that of Pelletier. Let the native carbonate be powdered, and passed through a fine sieve. Work it up with about an equal bulk of wheaten flour into a ball, adding a sufficient quantity of water. Fill a crucible of proper size, about one-third its height, with powdered charcoal; place the ball on this; and surround and cover it with the same powder, so as to prevent its coming into contact with the sides of the crucible. Lute on a cover; expose it for two hours to the most violent heat that can be raised in a wind furnace. Let the ball be removed when cold. On the addition of water, it will evolve great heat, and the baryta will be dissolved. The filtered solution, on cooling, will shoot into the crystals already described, p. 503.

6. Carbonate of baryta is decomposed by the sulphuric, nitric, muriatic, and various other acids, which detach the carbonic acid, and combine with the earth.

Borate of baryta is an insoluble white powder, which has not been particularly examined.

Phosphite of baryta may be obtained by adding muriate of baryta to phosphite of ammonia. No immediate precipitation ensues, but in 24 hours the glass is covered with a crust of phosphite of baryta, which may be edulcorated by water. According to Berzelius, it is constituted of such proportions, that its true constitution is probably 1 atom of acid = 20, + 1 atom of base = 78, + 1 atom of water = 9, and that its equivalent number is the sum of these, 107.

Hypo-phosphite of baryta is a very soluble salt, crystallizable with difficulty. (Dulong, Ann. de Chim. et de Phys. ii. 142.)

Phosphate of baryta. Phosphoric acid and baryta combine in various proportions.

The first or *neutral phosphate of baryta* is formed by mixing solutions of muriate of baryta and phosphate of soda. An insoluble precipitate is obtained, which, when edulcorated and dried, contains, according to Berzelius,

Phosphoric acid - -	31.8 - - -	100.00
Baryta - - - - - -	68.2 - - -	214.46
	100.	

But if, as is probable, the phosphate consists of 1 atom of acid + 1 atom of base, it ought to be composed of

Phosphorous acid - - -	26.62	or 1 atom = 28
Baryta - - - - - - - -	73.38	- - 1 atom = 78
	100.	Atomic wt. 106

By dissolving phosphate of baryta in phosphoric acid, and evaporating the clear solution, Berzelius obtained white crystals, which had an acid taste, and reddened vegetable blues. They are probably constituted of 2 atoms of acid = 56 + 1 atom of base = 78, together 134; and may therefore be considered as the *bi-phosphate.*

When a solution of these crystals is poured into alcohol, a bulky precipitate falls, which is white and tasteless. It appears to be constituted of 2 atoms of base and 3 of acid, or of 1 of the former and (so to speak) 1½ of the latter, and hence may be called a *sesqui-phosphate.*

Besides the above compounds, Berzelius has described two sub-phosphates of baryta. (Ann. of Phil. xv. 277.)

Sulphite of baryta may be formed by mixing sulphite of potassa and muriate of baryta. An insoluble compound is formed of

Acid - - - - - -	29.26 - - - - - -	100
Base - - - - - -	70.74 - - - - - -	241.7
	100.	

Hypo-sulphite of baryta may be obtained by adding muriate of baryta to a concentrated solution of hypo-sulphite of lime. It forms a white shining scaly powder, slightly soluble in water. According to Mr. Herschell, who alone has described it, it is a compound of 2 atoms of hypo-sulphurous acid = 48, + 1 atom of base = 78, and its equivalent number therefore is 126.

Sulphate of Baryta.

Baryta has a more powerful affinity than any other base for sulphuric acid, and its combination with that acid may therefore be effected with great facility, either by dropping the watery solution of baryta into diluted sulphuric acid, or into the solution of any of the alkaline sulphates. The new compound is extremely difficult of solution, requiring at least 43,000 times its weight of water, and it is not sensibly more soluble in hot than in cold water. In sulphuric acid, when concentrated and heated, it dissolves, but is again precipitated on pouring the solution into water.

It is owing to these properties that baryta, and several of its salts, are so much employed as tests of sulphuric acid, and as means of separating that acid from its combinations. By collecting the precipitate, first well edulcorated, then drying, igniting, and weighing it, and allowing 33.9 per cent. of its weight for real sulphuric acid, we learn the quantity of acid in any sulphate. This estimate is founded, not only on the theoretical constitution of the salt, *viz.*, 1 atom of acid + 1 atom of base, but on the coincidence of this with the best analyses. The following Table exhibits the experimental results of several chemists. Sulphate of baryta contains,

	Base.	Acid.
According to Klaproth	66.55	33.45
———— Mr. A. Aikin*	66.04	33.96
———— Mr. J. Thomson†	66.96	33.04
———— Berthollet‡	66.50	33.50
———— Berzelius§	65.59	34.41

I have already alluded (page 503) to the discordant statements, involving the composition of this sulphate, by Drs. Thomson and Berzelius. It is a subject which ought not to be left in doubt, since it affects every analysis in which sulphuric acid is concerned; but, till the question is settled by a decisive appeal to experiment, I shall retain the following proportional numbers:

Baryta, 1 atom	78	or 66.10
Sulphuric acid, 1 atom	40	or 33.90
Weight of its atom	118	100.

Sulphate of baryta is decomposed by alkaline carbonates, either by igniting a mixture of 1 part of the finely powdered sulphate with 3 of carbonate of potassa or soda, or by boiling together the pulverized sulphate and a solution of carbonate of potassa. Respecting this decomposition some curious facts have been ascertained by Dulong and by Mr. R. Phillips. These have been already stated in the chapter on Chemical Affinity (p. 72). They show that no quantity of carbonate of potassa, or soda, that can be employed at a single operation, is adequate to the entire decomposition of the sulphate of baryta. But by this process carbonate of baryta may, nevertheless, be procured in sufficient quantity for the purpose of preparing the pure earth, and its various salts, when the native carbonate cannot be had in sufficient abundance. The sulphate is found, in considerable masses, accompanying lead ore, in Derbyshire and other parts of England, where it is known by the names of cawk, ponderous spar, &c. The native sulphate is extremely heavy, having the specific gravity of 4.7. It occurs either in amorphous masses, or crystallized in a variety of forms, its primitive figure being a rhomboidal prism, the angles of which are 101° 42′ and 78° 18′. When applied to the purpose of obtaining the carbonate of baryta, it is to be finely powdered, mixed with three or four times its weight of carbonate of potassa, and boiled with a proper

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[*] Nicholson's Journal, xxii. 301.

[†] Ibid. xxiii. 174.

[‡] Memoires d'Arcueil, ii.

[§] 79 Ann. de Chim. 138.

quantity of water for a considerable time, in an iron kettle, stirring it, and breaking down the hard lumps, into which it is apt to run, by an iron pestle. It is then to be washed with boiling water as long as this acquires any taste. On the addition of dilute muriatic acid, an effervescence will ensue, and a considerable portion of the earth, probably along with some metals, will be dissolved. To the saturated solution add solution of pure baryta in water, as long as it disturbs the transparency of the liquor. This will throw down any metals that may be present; and the excess of baryta may afterwards be precipitated in the state of a carbonate, by a stream of carbonic acid. Decompose the muriatic solution by a pure alkaline carbonate; let the precipitated earth be well washed with distilled water; and, if the pure baryta is to be obtained from it, let it be treated as directed page 508.

Sulphate of baryta is also decomposed when strongly ignited with powdered charcoal, which abstracts the oxygen of the baryta and sulphuric acid, and leaves a combination of sulphur and barium. From this the baryta may be obtained by muriatic acid, as already directed, and the muriatic solution may be decomposed by carbonate of potassa.

The sulphate of baryta, when heated along with charcoal, affords one variety of solar phosphorus. This phosphorus has been called, from the place where the sulphate is found from which it was first prepared, the *Bolognian phosphorus*. The native sulphate, powdered after being ignited, and finely sifted, is to be formed into a paste with mucilage of gum arabic, and divided into cylinders or pieces of one-fourth of an inch in thickness. These, after being dried in a moderate heat, are to be exposed to the temperature of a wind furnace, placed in the midst of the charcoal. When the fuel is half consumed, it must be replenished, and suffered to burn out. The pieces will be found retaining their original shapes among the ashes, from which they may be separated by the blast of a pair of bellows. They must be preserved in a well-stopped phial.

This kind of phosphorus, after being exposed a few minutes to the sun's rays, shines in the dark sufficiently to render visible the dial of a watch. This property is lost by repeated use, but may be restored by a second calcination. It is probable that a partial decomposition of the sulphate takes place, and that sulphuret of barium is formed.

Seleniate of baryta.—Selenic acid is capable of uniting with baryta in two proportions. The neutral salt, which is insoluble, consists of 100 acid + 137.7 base; the *bi-seleniate*, which crystallizes in round transparent grains, and is soluble in water, is composed of 100 acid + 65 base.

Ferro-cyanate of baryta may be formed by adding prussian blue to a heated solution of baryta in water, till it ceases to be discoloured. The filtered solution deposits yellowish crystals, which have the figure of rhomboidal prisms, and are soluble in 1920 parts of cold, or 100 parts of boiling water. They dissolve in nitric and muriatic acids. Mr. Porrett, who has analyzed them, states them to consist of

Acid - - - - - - - -	34.31
Base - - - - - - - -	49.10
Water - - - - - - - -	16.59
	100.

SECTION VI.

Of Strontium.

Strontium may be procured by exactly the same process as barium, substituting the native carbonate of strontia for that of baryta. (See p. 502.) It was first obtained by Sir H. Davy in 1808, but in very minute quantities. It resembles barium, has not a very high lustre, is difficultly fusible, and not volatile. It is converted into strontia by exposure to air, or by contact with water.

Strontia.

According to Stromeyer, 100 of strontium combine with 18.10 of oxygen, which numbers are in the proportion very nearly of 44 to 8. Dr. Thomson, from his experiments, deduces 6.5 for the weight of the atom of strontia, oxygen being 1, corresponding with 52 when hydrogen is taken as unity; and from this, deducting 8, we again obtain 44 for the atom of strontium. With this result, that of Berzelius agrees so nearly, that it will probably be near the truth to consider strontia as represented by 52, and its base by 44. Hence strontia will consist of

Strontium - -	84.54	or 1 atom	44
Oxygen - - -	15.46	or 1 atom	8
	100.		52

Properties of Strontia.

Strontia (so called from Strontian, in Scotland, where it was first discovered in combination with carbonic acid) may be prepared either by subjecting the carbonate to a strong heat in a crucible, or by igniting the nitrate in a porcelain retort or other close vessel. A grey substance remains, which becomes very hot on the affusion of water; and when more water is added, and heat applied, a considerable proportion of the earth is dissolved. On cooling, the solution deposits regular crystals; but the shape of these differs considerably from that of barytic crystals. The crystals of strontia are thin quadrangular plates, sometimes square, oftener parallelograms; not exceeding in length, and not reaching in breadth, a quarter of an inch. Their primary form is a right square prism. (See Mr. Brooke's figure, Ann. of Phil. N. S. vii. 287.)

These crystals undergo, by the action of heat, much the same changes as those of baryta; and leave only about 32 per cent. of the dry earth. One part of the crystals requires about 51⅓ of water at the temperature of 60° for solution, but boiling water takes up half its weight. Mr. Dalton states that the crystals consist of 1 atom of strontia and 12 atoms of water.

Boiling alcohol, in which these crystals have been dissolved, burns with a blood-red flame.

Strontia does not combine with alkalies. Baryta has, probably, no affinity for it; for no precipitation ensues, on mixing the watery solutions of the two earths.

From the preceding enumeration of its characters, it appears that strontia differs from baryta in the form of its crystals, which contain also more combined water, and are less soluble than those of baryta; and also in affording, with alcohol, a flame of different colour. These distinctions were derived by Dr. Hope, from his excellent series of experiments on the two earths. (Edinb. Trans. vol. iv.) It is remarked, also, by Fontenelle and Quesneville, that on adding a few drops of concentrated sulphuric acid to baryta, that oxide exhibits a vivid incandescence, and the vessel in which the experiment is made is broken, while with strontia similarly treated a much less degree of heat is excited. (37 Ann. de Ch. et de Ph. 223.) Other circumstances of distinction, derived from the properties of their respective salts, will be stated hereafter.

Chloride of strontium may be formed either by heating strontia in chlorine gas, which disengages oxygen; or by dissolving carbonate of strontia in muriatic acid, and evaporating to dryness. The product is a compound, according to Dr. Thomson, of 55 strontium to 45 chlorine, which are as nearly as possible in the proportion of 44 to 36, numbers agreeing with the weights of their respective atoms. When the chloride is converted into a muriate by the action of water, the resulting compound must, therefore, consist of 52 strontia + 37 acid. Hence we have the composition of these two salts as follows:

Chloride of strontium,

Strontium	55	or 1 atom	44
Chlorine	45	or 1 atom	36
	100	Weight of its atom	80

And muriate of strontia, (anhydrous) of

Strontia	58.42	or 1 atom	52
Acid	41.58	or 1 atom	37
	100.	Weight of its atom	89

Muriate of strontia crystallizes in long slender hexagonal prisms, which are soluble in two parts of water at 60°, and to almost any amount in boiling water. In a very moist atmosphere, they deliquiate. They dissolve in alcohol, and impart to it the property of burning with a blood-red flame. By exposure to a red heat, 134 grains of these crystals lose 54; but of this loss 9 grains may be traced to the union of 1 atom (= 8) of oxygen with 1 atom (= 1) of hydrogen, by which the muriate is converted into a chloride. The remainder, 54 — 9 = 45, shows the real loss of water existing as such in the crystals, which are therefore constituted of

Anhydrous muriate -	66.42 or 1 atom	89
Water - - - - - -	33.58 or 5 atoms	45
	100.	134

Chlorate of strontia may be obtained by the direct action of chloric acid on carbonate of strontia. It is a deliquescent salt, having an astringent taste, and communicating to the flame of alcohol a fine purple tint.

Hydriodate of strontia is extremely soluble, and crystallizes in very slender prisms. Heated a little below redness in a close vessel, it is transformed into *iodide of strontium.*

Iodate of strontia is an insoluble compound, requiring some hundred parts of water for solution. At a red heat it is decomposed into oxygen, iodine, and strontia.

Nitrate of strontia.—This salt may be obtained in the same manner as the nitrate of baryta. Its crystals are dissolved by their own weight of water at 60°, or by little more than half their weight of boiling water. When applied to the wick of a candle, or added to boiling alcohol, they communicate to the flame a deep blood-red colour. They are decomposed by a high temperature, and afford pure strontia. Exclusive of water, the salt consists, according to Richter, of 51.4 acid + 48.6 base; or, according to Stromeyer, of 50.62 acid + 49.38 base, proportions agreeing with the weights of the atoms of its ingredients. The forms of the crystals of this salt, and also of another variety which is anhydrous, have been given by Mr. Brooke (Ann. of Phil. N. S. vii. 288). In both, the acid and base appear, from the analysis of Mr. Cooper, to be united atom to atom, but the water assigned to the hydrous variety is not in atomic proportion.

Carbonate of strontia.—The relation of strontia to carbonic acid resembles very nearly that of baryta; and all the experiments, directed to be made with the solution of the latter earth, may be repeated with that of strontia, which will exhibit similar appearances.

The carbonate of strontia requires for solution 1536 parts of boiling water. It is found native, but containing a little carbonate of lime, at Strontian, in Argyleshire; and may, also, be prepared by artificial processes, which will be afterwards described. From this carbonate pure strontia may be obtained, by treating it in the same manner as was directed for the calcination of carbonate of baryta. (See p. 508.)

The artificial carbonate, according to Stromeyer, (Ann. de Chim. et de Phys. iii. 396,) does not essentially contain any water. It consists of

Strontia - - - -	70.313	or	100.
Carbonic acid - -	29.687	or	42.22
	100.		

These scarcely differ from its theoretical proportions; *viz.*, 1 atom of strontia = 52 + 1 atom of carbonic acid = 22, together 74; or 70.09 + 29.91 = 100.

Borate of strontia is described by Dr. Hope as a white powder, soluble in about 130 parts of boiling water, and changing syrup of violets to green.

Phosphite of strontia has not been examined.

Hypo-phosphite of strontia is a very soluble salt, which is with difficulty made to crystallize.

Phosphate of strontia may be formed by mixing solutions of muriate of strontia and phosphate of soda. It is tasteless, insoluble in water, but soluble in an excess of phosphoric acid; fusible by the blow-pipe into a white enamel; and decomposable only by sulphuric acid. It consists, according to Stromeyer, of

Acid - - - - - - - - -	36.565
Base - - - - - - - - -	63.435
	100.

If a true binary compound, it should consist of very nearly 65 base + 35 acid. Besides this salt, there is also a *bi-phosphate*, consisting of 2 atoms of acid, 1 of base, and 2 of water.

Sulphuret of strontium may be formed either by fusing in a green glass tube three parts of dry strontia with one of sulphur, or by strongly igniting the sulphate with one-seventh or one-eighth its weight of charcoal. By solution it is converted into hydro-sulphuret and hydrogureted sulphuret of strontia. These are separable from each other, if the solution be evaporated with the exclusion of air; for the hydro-sulphuret forms crystals which have a white silky lustre, while the hydrogureted sulphuret remains in solution.

Sulphite of strontia is not known.

Hypo-sulphite of strontia.—Mr. Herschell formed this salt by passing a current of sulphurous acid through hydrogureted sulphuret of strontia. It has a bitter taste; dissolves in about 1¾ times its weight of water; is insoluble in alcohol; dissolves chloride of silver with great facility; and when heated *per se* becomes white, and then burns with a faint flame.

Sulphate of strontia.—This salt resembles very nearly the sulphate of baryta. It may be formed in a similar manner, by pouring a solution of the pure earth into diluted sulphuric acid, or into the solution of an alkaline sulphate; for strontia has a stronger affinity than any of the alkalies for sulphuric acid. It is soluble in 38.40 parts of boiling water.

The sulphate of strontia is also found native in considerable quantities; chiefly at Aust Passage, and at other places in the neighbourhood of Bristol. As the native carbonate is rather scarce, this compound may be advantageously employed for procuring artificial carbonate of strontia. The process is precisely similar to that already described for decomposing the sulphate of baryta.

According to a considerable majority of the chemists who have analyzed it, sulphate of strontia consists of

Acid	42	100
Strontia	58	158
	100	258

From these numbers its equivalent has been deduced by Dr. Wollaston. But Vauquelin has stated, that it is composed of 46 acid and 54 base, and Stromeyer of 43 acid and 57 base. The theoretical constitution of 1 atom of acid + 1 of base, would require it to consist of 43.47 acid + 56.53 base.

Seleniate of strontia.—The *neutral seleniate* is white and insoluble; the *bi-seleniate* dissolves with difficulty even at a boiling temperature.

Ferro-cyanate of strontia is a salt which dissolves in less than four parts of cold water, but has not been made to crystallize. It is not deliquescent.

SECTION VII.

Of Magnesium.

The base of magnesia, for which Sir H. Davy has proposed the term *magnesium*, is very imperfectly known. In the attempts to distil its amalgams, the metal seemed to act upon the glass, even before the whole of the quicksilver was distilled from it. In one experiment, in which the process was stopped before the mercury was entirely driven off, it appeared as a solid, having the same whiteness and lustre as the other metals of the earths. It sank rapidly in water, though surrounded by globules of gas, and produced magnesia. In the air it quickly changed, falling into a white powder, which proved to be magnesia. This earth Berzelius states, in round numbers, to consist of 38 or 39 per cent. oxygen, and 61 or 62 magnesium. This would make the weight of its atom 15.5, and that of magnesia 23.5. Dr. Thomson's experiments (Ann. of Phil. N. S. vol. i. p. 5) give 20 for the equivalent of magnesia, from which, if 8 be subtracted, there results 12 for the atom of magnesium. Perhaps it will be sufficiently near the truth to consider it as represented by that number.

Magnesia.

Magnesia possesses the properties of an alkali, but in a considerably less degree than any of the foregoing earths. Its characters are as follow:

When perfectly pure, it is entirely destitute of taste and smell. Its specific gravity is between 2 and 3.

No heat is excited by the affusion of water, and only a very small proportion is dissolved, not exceeding 1-5142d of its weight at 60°, or 1-36000th at 212°, according to Dr. Fyfe's experiments. Magnesia appears, however, to have an affinity for water; for when moistened, and afterwards dried, its weight is found increased in the proportion of 118 to 100.

When precipitated also by pure potassa or soda from any of its salts, it falls down in union with water as a *hydrate*, which, when dried by a very gentle heat, forms transparent masses. In this state, according to Davy, it contains about $\frac{1}{3}$ of its weight of water; but, according to Berzelius, 100 parts of magnesia combine with 142 to 144 of water. None of these proportions exactly agree with the atomic weights of water and magnesia; though the numbers of Berzelius approach very nearly to those of a compound of 3 atoms of water (27) with one of magnesia (20). It is probable, indeed, that magnesia and water unite in several proportions. The native hydrate, analyzed by Dr. Fyfe, contained 69.75 base + 30.25 water. (Ann. of Phil. N. S. i. 396.) If these numbers be altered to 68.5 of the former + 31.5 of the latter, they will agree exactly with the proportion of 1 atom of magnesia to 1 atom of water, constituting the *proto-hydrate*.

Magnesia reddens turmeric, and changes to green the blue colour of the violet; but water which has been agitated with magnesia, when filtered through paper, does not produce similar effects. In these respects magnesia differs from lime, and approaches to those earths which are destitute of decidedly alkaline qualities.

Magnesia is not dissolved by liquid alkalies, nor by alkaline earths; and, in the dry way, it has no affinity for baryta or strontia.

Magnesia is by no means a rare production of nature, for though very seldom found in a state approaching to purity, yet it enters largely into some rocks that compose extensive formations, such as serpentine, steatite, magnesian lime-stone, &c.; and in combination with sulphuric and muriatic acids it forms a large proportion of the ingredients of sea water. Its principal use is in medicine, for hitherto it has not been extensively applied to any of the practical arts.

Chloride of magnesium may be formed by heating pure magnesia in chlorine gas. This compound is little known.

Chloride of magnesia may be prepared by passing chlorine gas into water, in which magnesia is kept mechanically suspended, or by the mixture of solutions of chloride of lime and sulphate of magnesia. It has not yet been accurately investigated. It has been used with advantage in some of the processes of bleaching and calico printing.

Chlorate of magnesia is also little known.

Muriate of magnesia is a deliquescent and very soluble salt, of an intensely bitter taste, soluble in alcohol. It forms regular crystals, which consist of

Muriatic acid - - -	36.27	or 1 atom	= 37
Magnesia - - - -	19.60	or 1 atom	= 20
Water - - - - -	44.13	or 5 atoms	= 45
	100.		102

This salt cannot be reduced to chloride of magnesium by heat, for the effect of heating it strongly is to expel a part of the acid.

Acid	42	100
Strontia	58	138
	100	238

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Water - - - - -	44.13	or 5 atoms	= 45
	100.		102

This salt cannot be reduced to chloride of magnesium by heat, for the effect of heating it strongly is to expel a part of the acid.

It constitutes about one-eighth of the solid ingredients of sea water, in which, as I have shown (Phil. Trans. 1810), and as Dr. Marcet has since observed (Phil. Trans. 1822), it is free from any admixture of muriate of lime.

A triple muriate of potassa and magnesia was obtained by Dr. Marcet in rhombic crystals from the bittern, or mother-liquor, of sea water; but the constitution of this salt was found to be so delicate, that it was liable to be separated into muriate of potassa and muriate of magnesia by water alone, and was with certainty decomposed by alcohol, which took up the magnesian muriate only. (Phil. Trans. 1822, p. 456.)

Hydriodate of magnesia is deliquescent, and abandons its acid when heated.

When *iodine* is heated along with magnesia and water, both hydriodate and iodate of magnesia are formed. By concentrating the solution, both salts are partly decomposed; and a flocculent iodide of magnesia is formed, resembling kermes in its appearance, which, when heated, loses part of its iodine, and is changed into a subiodide.

Nitrate of Magnesia.

This compound may be prepared, by dissolving carbonate of magnesia in diluted nitric acid. The solution, when evaporated, yields crystals in the shape of prisms, with four oblique faces truncated at their summits. Most commonly, however, it forms a shapeless mass, consisting of an immense number of small needle-shaped crystals, crossing each other irregularly. These crystals deliquiate in the air, and are soluble in half their weight of water. When exposed to the heat of ignition, they fuse; a few bubbles of oxygen gas first escape; and the nitric acid then passes undecomposed. The salt contains, according to Dr. Thomson,

1 atom of nitric acid - - -	54
1 atom of magnesia - - -	20
6 atoms of water - - - -	54
	128

Ammonia-nitrate of magnesia may be obtained by mixing the solutions of nitrate of ammonia and nitrate of magnesia, and evaporating the solution. The crystals are prisms, which are soluble in about 11 parts of water at 60°, and are less deliquescent than either of the component salts.

Carbonate of Magnesia.

Pure magnesia does not attract carbonic acid with nearly the same intensity as lime. Hence magnesia may be exposed to the air, without any important change in its properties, or much increase of weight, unless the exposure be long continued, when it first becomes a hydrate by absorbing water, and then attracts carbonic acid from the atmosphere. The carbonate of magnesia, used in medicine, and for experimental purposes, is prepared by a process to be described in speaking of the sulphate. In this state, however, it is not a true binary compound of acid and base; but its composition varies, as it has been precipitated with or without heat. If the former, it contains, according to Bucholz, 42 base, 35 acid, 23 per cent. water; if prepared from cold solutions of carbonate of soda and sulphate of magnesia, it consists of 33 base, 32 acid, and 35 water. Mr. Dalton states it to be composed of 43 base, 40 acid, and 17 water. Berzelius is of opinion that it is a compound of 3 atoms of carbonate of magnesia with 1 atom of the quadro-hydrate of the same earth; (Thomson's First Princ. ii. 303;) and if, as appears to me probable, this be the correct view of its atomic composition, it will consist of

3 atoms of carbonate - - -	42 × 3 =	126 -	69.2
1 atom of quadro-hydrate -	20 + 36 =	56 -	30.8
		182	100.

Or, of

Magnesia in the carbonate - -	32.93	43.93
Ditto in the hydrate - - - -	11.	
Carbonic acid - - - - - - - - - -		36.32
Water - - - - - - - - - - - - -		19.75
		100.

The true carbonate of magnesia, consisting of 1 atom of acid + 1 atom of base, though it has not yet been formed artificially, is found as a natural product, and, being entirely without water, may be called the *anhydrous carbonate of magnesia.* A specimen of this mineral from the East Indies, I have analyzed and described in the Annals of Phil. N. S. i. 252.

The saturated carbonate of magnesia (as it has generally been considered), may be obtained, by passing streams of carbonic acid gas through water, in which common magnesia is kept mechanically suspended, or by adding a very dilute solution of carbonate of soda, highly charged with carbonic acid under pressure, to a dilute solution of sulphate of magnesia. No immediate precipitation ensues, but, after a few days, congeries of crystals will be found adhering to the inner surface of the glass vessel. Their form is described by Mr. Brooke. (Ann. of Phil. N. S. vi. 375.) Some of these, prepared by myself, I analyzed several years ago, and showed them to consist of base 29, acid 30, water 41. Berzelius, from the examination of a specimen probably purer than mine, deduced its proportions to be, base 29.583, acid 31.503, water 38.914. (Edinb. Phil. Journ. i. 73.) There can be little doubt that its true constitution is as follows, and that it is a carbonate, and not, as has been supposed, a *bi-carbonate*, a salt which, in fact, has not yet been proved to exist, *viz.*,

1 atom of magnesia - - -	20 - -	28.60
1 atom carbonic acid - - -	22 - -	32.
3 atoms water - - - - -	27 - -	39.40
	69	100.

Water at 60° dissolves only 1-2493d of its weight, and, at the boiling temperature, 1-9000 part of common carbonate of magnesia. (Edinb. Journ. v. 305.) The addition of almost any acid to the carbonate expels its carbonic acid, and a compound remains of magnesia with the new acid which has been added. The affinity of carbonic acid for magnesia appears, indeed, to be feeble, for it is expelled by a very moderate heat, much inferior to that required for the decomposition of carbonate of lime. The residue is pure magnesia, which, for medicinal and chemical uses, is always prepared by the calcination of the carbonate, and hence its name of *calcined magnesia.*

Carbonate of magnesia precipitates lime from lime-water, a carbonate of the latter earth being formed in consequence of its greater affinity for carbonic acid.

Carbonate of magnesia and potassa.—Berzelius has described a salt with double base, which may be formed by mixing bi-carbonate of potassa in excess with muriate of magnesia. (Edinb. Phil. Journ. ii. 67.) No precipitate appears, but in a few days the salt arranges itself in crystalline groups on the sides of the vessel. It consists of

Potassa - - - - - - - - -	18.28
Magnesia - - - - - - - -	15.99
Carbonic acid - - - - - - -	34.49
Water - - - - - - - - -	31.24
	100.

Borate of magnesia may be formed by dissolving magnesia in boracic acid. It precipitates in small irregular crystals, sparingly soluble in water, but soluble in acetic acid. A natural compound of boracic acid and magnesia, with a proportion of lime, is found near Luneburg in Germany, and known by the name of *boracite.* This appears to be composed of 2 atoms of boracic acid and 1 atom of magnesia, or to be a true *biborate.* (Thomson, First Prin. ii. 504, and Arfweds. 10 Ann. Ph. 126.)

Phosphate of magnesia may be formed either directly by dissolving carbonate of magnesia in phosphoric acid, or by mixing solutions of sulphate of magnesia and phosphate of soda. No immediate change ensues, but, after a few hours, large transparent crystals of phosphate of magnesia make their appearance in the solution. The crystals require 15 parts of cold water, but a smaller proportion of boiling water, for solution. They effloresce in the air, and, when heated, leave a dry powder which is fusible into a transparent glass. They are constituted of 1 atom of acid, 1 of base, and 7 of water. (Thomson.)

Ammonia-phosphate of magnesia may be prepared by mixing solutions of phosphate of ammonia and phosphate of magnesia, or any other soluble salt with base of that earth. It falls down in the form of a white insoluble powder; but, in certain varieties of urinary calculi, it is found lining cavities of the concretions, in a distinctly crystallized form, and it is deposited in crystals on the sides of vessels in which urine is long kept. It is tasteless, scarcely soluble in water, readily soluble in dilute acids, and is decomposed by heat, leaving phosphate of magnesia only. According to Fourcroy, it contains equal weights of phosphate of ammonia, phosphate of magnesia, and water.

Sulphuret of magnesia.—It does not appear that magnesia forms a permanent union with sulphur, for, when heated together, the latter sublimes.

Hydro-sulphuret of magnesia.—This earth is soluble in water impregnated with sulphureted hydrogen, but the properties of the compound have not been investigated. The same may be said of the hydroguretted sulphuret.

Sulphite of magnesia may be prepared by saturating carbonate of magnesia with sulphurous acid; but the sulphite, which is first formed, is insoluble till an excess of acid is added, when it dissolves, and may be crystallized by slow evaporation. It is soluble in 20 parts of cold water, but hot water takes up a larger portion, and deposits it again on cooling. The crystals effloresce in the air, and are slowly changed into sulphate.

Hypo-sulphite of magnesia may be obtained by boiling a solution of sulphite of magnesia with flowers of sulphur. The salt crystallizes when the solution has cooled. It is intensely bitter, and readily soluble in water, but is not deliquescent. When heated, it burns with a blue flame, and, by a sufficient continuance of the heat, the whole of the acid is expelled, and magnesia remains.

Sulphate of Magnesia.

When highly-concentrated sulphuric acid is suddenly added to fresh prepared and pure magnesia, very great heat and vapour are excited, and are accompanied frequently with an extrication of light; an appearance first observed by Westrumb. But if the carbonate of magnesia be added to diluted sulphuric acid, the carbonic acid is expelled, no heat is evolved, and a solution of sulphate of magnesia is formed, which crystallizes on evaporation and cooling. Crystals of sulphate of magnesia may also be procured in the shops, under the name of Epsom salt.

These crystals have the following properties:

Their primary form may be regarded as a right prism with a rhombic base, whose angles are 90° 30' and 89° 30'. One cleavage only has been found, which is parallel to the short diagonal of the prism, and consequently to the plane *h* of the accompanying figures.

Fig. 1.

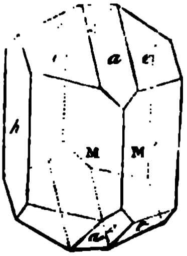

Fig. 1 represents a crystal of a form which frequently occurs, and of which the following are the measurements:

M on M' - - - -	90°	30'
M on *h* - - - -	134	45
M on *c* - - - -	129	00
a on *a'* - - - -	120 nearly	

Fig. 2.

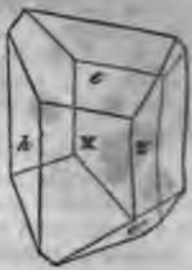

Fig. 2 represents a form under which the crystals also frequently appear. In this form only two of the four planes *e* are seen on each summit, and alternating in position as shown in the figure. On some of the crystals, however, which resemble this figure, the two other planes *e* may be perceived, but they are very minute.

2. At the temperature of 60°, this salt is soluble in an equal weight of cold water, and in three-fourths its weight of boiling water, which thus receives an addition of one-fourth of its bulk.

3. When exposed to a low red-heat, it undergoes the watery fusion, but is not volatilized. It loses, however, rather more than one-half its weight, which is water of crystallization, and, according to Berzelius, a very minute portion of acid escapes.

The dry salt is constituted of

1 atom of magnesia - -	20	- 33.04	- 100
1 atom of sulphuric acid	40	- 66.96	- 202
	60	100.	

And the crystals contain,

Magnesia - -	16.	- - or 1 atom	= 20
Sulphuric acid	32.57	- - or 1 atom	= 40
Water - - -	51.43	- - or 7 atoms	= 63
	100.	Weight of its atom	123

4. Its solution is precipitated by carbonates of potassa and of soda; but not by the bi-carbonates of those bases, nor by carbonate of ammonia, unless heat is applied. The carbonate of magnesia of the shops is prepared by mixing together concentrated and hot solutions of carbonate of potassa and sulphate of magnesia. The sulphate of potassa, thus formed, is removed by copious washing with water, and the carbonate of magnesia is then dried. The proportions employed are filtered solutions of 4 parts of the crystallized sulphate, and 3 of the carbonate of potassa. One hundred parts of the desiccated sulphate give about 71 of the mixed carbonate and hydrate of magnesia, or about 33 of the pure earth.

When solution of pure ammonia is added to that of sulphate of magnesia, part of the earth is precipitated. The rest remains in solution, and, by evaporation, a triple salt is formed, consisting of sulphuric acid, magnesia, and ammonia, called *ammoniaco-magnesian sulphate.* The form of its crystals is described in the Ann. of Phil. N. S. vii. 117. It is constituted (Thomson's First Princ. ii. 419) of

Sulphate of magnesia - - -	1 atom	60
Sulphate of ammonia - - -	1 atom	57
Water - - - - - - - - -	7 atoms	63
		180

A compound *sulphate of magnesia and soda* has been described by Dr. Murray, in a note to his paper on the Analysis of Sea Water. (Edinb. Trans.) It crystallizes in rhombs truncated on the angles and edges; is soluble in rather more than three times its weight of water at 60° Fahrenheit; is permanent in the air; and does not fuse, but decrepitates on applying heat. It is composed of

Sulphate of magnesia	32	or 1 atom	= 60
Sulphate of soda - -	39	or 1 atom	= 72
Water of crystallization	29	or 6 atoms	= 54
	100		186

Sulphate of potassa and magnesia was composed by Link by saturating bi-sulphate of potassa with magnesia. The taste of this triple salt is bitter; in solubility it nearly agrees with sulphate of potassa; its crystals, the form of which is described, Ann. of Phil. vi. 41, consist of 1 atom of sulphate of potassa, 1 of sulphate of magnesia, and 7 atoms of water. It has been found by Dr. Marcet to be an ingredient of sea water. (Phil. Trans. 1822, p. 455.)

Seleniate of magnesia.—Selenic acid unites with magnesia in two proportions, forming a seleniate and a bi-seleniate, but the compounds have no particularly interesting properties.

SECTION VIII.

Glucinum.

Glucinum has been obtained by Wöhler by acting upon its chloride with potassium. For this purpose, the chloride was prepared, according to a process of Henry Rose: Glucina, which had been obtained from the beryl, was intimately mixed with charcoal, and the mixture, heated to redness, was exposed to a current of chlorine gas. The chloride was put into a covered platinum crucible, in alternate strata with flattened fragments of potassium, and heated by a spirit lamp. The decomposition took place with the evolution of intense heat. A grey mass remained, from which water extracted chlorides of potassium and glucinum; the glucinum remaining as a dark grey powder, which had the appearance of a metal precipitated in very divided parts. Under the burnisher, it took a dull metallic lustre. It appeared difficult of fusion. It was not oxidable at common temperatures either by air or by water, nor by the latter even when boiling. When made red-hot on a piece of platinum foil, it burnt brilliantly, and was re-converted into glucina of a perfectly white colour. In oxygen gas it burned with extraordinary brightness, and also in chlorine, in iodine, and in bromine. Its combination with sulphur, selenium, phosphorus, and arsenic, also took place with vivid light. The quantity of oxygen absorbed by its combustion does not appear to have been ascertained. (Ann. de Ch. et de Phys. Sept. 1828.)

Glucina.

This earth was discovered by Vauquelin, in the year 1798. He obtained it from the *aqua marina* or *beryl*, a precious stone of a green colour, and very considerable hardness, which is found crystallized in Siberia. Glucina has since been discovered to form rather more than one-fifth the weight of a crystallized mineral called *euclase*. The following process may be employed to separate it from the beryl:

Let the stone, reduced to a fine powder, be fused with three times its weight of pure potassa. To the fused mass add a quantity of water, and afterwards diluted muriatic acid; which last will effect a complete solution. Evaporate the solution to dryness, re-dissolve the dry mass, and add carbonate of potassa so long as any precipitation ensues. Dissolve the precipitate in sulphuric acid; add a little sulphate of potassa; and, on evaporation, crystals of alum will be obtained. By this process the alumina is detached. The residuary liquor, which yields no more crystals, contains the glucina, and a small portion of alumina. Add a solution of carbonate of ammonia to excess; this will throw down the alumina, and the glucina will remain dissolved by the superabundant carbonate. When this solution is evaporated to dryness, and moderately heated, the alkaline carbonate is expelled, and a carbonate of glucina remains, in the proportion of 16 parts from every 100 parts of the stone.

Glucina has the following properties:

1. It is a fine white and soft powder, resembling alumina in its sensible properties; and, like that earth, adhering to the tongue. Its specific gravity is 2.97.
2. It has no action on blue vegetable colours.
3. It does not harden, or contract, like alumina, by heat; and is infusible.
4. It is insoluble in water, but forms with it a ductile paste.
5. It is soluble in liquid potassa and soda, but not in the solution of pure ammonia. In these respects it agrees with alumina.
6. Glucina is soluble in carbonate of ammonia; a property distinguishing it from alumina.
7. It appears, like alumina, to have an affinity for colouring matter.
8. With the different acids it forms combinations, which have a sweet and rather astringent taste. Hence its name has been derived from γλυκυς, signifying sweet.
9. It is not precipitated by triple prussiate of potassa.

The atomic weight of glucina is deduced by Dr. Thomson, from his own experiments and those of Berzelius, to be 26; and supposing it to consist of an atom of metallic base and an atom of oxygen, the atom of glucinum will weigh 26 — 8 = 18. (Thomson's First Princ. i. 318.)

SECTION IX.

Yttrium.

The base of yttria has been extracted by Wöhler by a process precisely similar to that employed for separating glucinum; but there appears to be much more difficulty in obtaining yttrium pure. The heat, developed by the action of potassium on chloride of yttria, is very intense. The result, after separating what is soluble by water, is a metal of an iron-black colour, in scaley particles, of a perfectly metallic lustre. The fragments appeared to be brittle, not like aluminum ductile. At common temperatures, yttrium is not combustible in air, nor oxidable by water. Heated to redness it burns in the air, and its combustion in oxygen is one of the most brilliant that can be exhibited. The proportion of oxygen taken up by a given weight of metal, does not appear to have been determined. Its remaining properties closely resemble those of glucinum.

Yttria, or Ittria.

This earth was discovered in 1794, by Professor Gadolin, in a stone from Ytterby in Sweden; and its title to the character of a peculiar earth rests, also, on the unquestionable authority of Klaproth and Vauquelin, both of whom have made it the subject of experiment. The following process for obtaining it, is described by Vauquelin in the 36th volume of the *Annales de Chimie*, p. 150.

Fuse the pulverized stone (called Gadolinite) in the manner already described, with twice its weight of potassa; wash the mass with boiling distilled water, and filter. The filtered solution, which has a beautiful green colour, yields, during evaporation, a black precipitate of oxide of manganese. When this has ceased to appear, allow the liquor to stand; decant the clear part, and saturate with nitric acid. Let the insoluble part be, also, digested with extremely dilute nitric acid, which will take up the soluble earths only, and will leave, undissolved, the silica and oxide of iron. Let the two portions be mingled together, and evaporated to dryness; then re-dissolved and filtered; by which means any remains of silica and oxide of iron are separated. To obtain the yttria from the nitric solution, it would be sufficient, if no other earth were present, to precipitate it by carbonate of ammonia; but small portions of lime, and of oxide of manganese, are still present along with it. The first is separated by a few drops of carbonate of potassa; and the manganese, by the cautious addition of hydro-sulphuret of potassa. The yttria is then to be precipitated by pure ammonia, washed abundantly with water, and dried.* It amounts to about

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* Nicholson's Journal, xviii. 77. Wöhler, to whom it was important to obtain pure yttria for the preparation of yttrium, remarked that it was difficult to procure it quite free from sulphuric acid and potassa, from which sulphur and potassa were developed along with the metallic base.

35, or according to Berzelius 45, per cent., of the weight of the stone. It has been found also to form about one-fifth of the weight of *yttrotantalite*, and about one-twelfth of that of *yttrocerite*.

Yttria has the following properties:

1. It is perfectly white; but it is difficult to preserve it free from a slight tinge of colour, owing to its contamination with oxide of manganese.

2. It has neither taste nor smell; and it is smooth to the touch, like alumina.

3. It is insoluble in water, and infusible except by an intense heat.

4. It is very ponderous; its specific gravity being 4.842.

5. It is not attacked by pure alkalies; and, in this respect, it differs from glucina and alumina, both of which are abundantly soluble in fixed alkalies.

6. Like glucina, it is soluble in carbonate of ammonia, but five or six times less so than that earth; or, in other words, of equal quantities of glucina and yttria, the latter requires for solution five or six times more of the carbonate of ammonia than the former.

7. It is soluble in most acids; and is precipitated by pure alkalies, by baryta, and by lime.

8. From these solutions it is also precipitated by the oxalic acid, and by oxalate of ammonia, in a state resembling fresh precipitated muriate of silver. Prussiate of potassa throws it down in small white grains passing in a short time to pearl grey; phosphate of soda in a white gelatinous form; and infusion of galls in brown flocculi.

9. Yttria, which has been a long time exposed to the action of fire, gives out chlorine gas, when dissolved in common muriatic acid; thus manifesting one property of a metallic oxide.

The atomic weight of yttria, deduced by Dr. Thomson from the composition of its salts, is 42, and that of yttrium, supposing the earth to consist of an atom of base and an atom of oxygen, will be 42 — 8 = 34.

SECTION X.

Aluminum.

The experiments of Sir H. Davy afforded a strong presumption that alumina is a metallic oxide; but he did not obtain its base in such a state of separation, as to enable him to investigate its properties. Alloys, however, were formed with it, which gave sufficient evidence of its existence. Oersted attempted to exhibit aluminum in a detached form, by employing the chloride of that earth (Ann. of Phil. Nov. 1827, p. 391); but did not obtain distinct results. Wöhler has since availed himself of the hint afforded by Oersted, and has succeeded in his attempts to exhibit, in the most satisfactory manner, the metallic base of alumina, by acting upon the chloride of aluminum.

Chloride of aluminum.—This salt may be easily prepared by the process used by Oersted. Alumina, precipitated from alum by carbonate of potassa in excess, is well washed, dried, and mixed, in the state of hydrate, with powdered charcoal, oil, and sugar, into a thick paste, which is to be heated in a covered crucible till all the vegetable matter is destroyed. The black matter which remains is, while still hot, to be put into a porcelain tube properly arranged in a convenient furnace; and through this, chlorine gas, desiccated by fused chloride of calcium, is to be passed into a small tubulated glass balloon, attached by a glass tube to the other end of the porcelain tube. When the apparatus is filled with chlorine, the porcelain tube is to be raised to a red heat, and then the chloride will begin to appear in the balloon in a pulverulent form. A small portion also escapes with the oxide of carbon which is evolved, and causes it to fume in the air. At the expiration of an hour, or a little more, the tube will be obstructed by the chloride, and the operation may then cease. On taking the apparatus to pieces, after cooling, the chloride is found at the end of the tube issuing from the furnace, partly in a crystalline form, and partly in a solid hard mass, which is easily detached. It is of a pale yellowish green colour, semi-transparent, and in talcose plates. It fumes a little in the air, evolves a smell of muriatic acid, and is resolved into a clear liquid. When added to a small quantity of water, it is dissolved, and produces considerable heat. It is volatile a little above 212°, and fusible nearly at the same temperature. It may be preserved unchanged in naphtha, and even fused under it into a liquid of a brownish red, and is then not acted upon by contact with potassium. When heated in a tube of glass with sulphureted hydrogen, it absorbs 30 or 40 times its volume of the gas, and gives it out again when added to water.

Aluminum.—A small fragment of the chloride, heated in a glass tube with potassium, occasions so intense a heat as to break the tube; but the process may safely be performed in a covered platinum crucible, taking care to use not more than from six to ten small pellets of potassium, each about the size of a pea, and not more of the chloride than will be volatilized by the reduction. A fused mass remains of a greyish-black colour. To detach this, the crucible must be plunged into a vessel of water; a slight escape of hydrogen takes place, of a very offensive odour, and a grey powder is left, which on minute examination, especially in the direct rays of the sun, is evidently composed of very small metallic plates, somewhat resembling platinum. This powder, sufficiently washed with cold water, and then dried, is aluminum. (Ann. de Ch. et de Ph. Jan. 1828.)

The colour of this metal is tin-white, especially when compresed in a mortar, and rubbed with a burnisher. Its aspect is decidedly metallic, in which respect it differs from silicium. It is infusible at the heat at which cast-iron melts. It does not conduct electricity; but this is probably owing merely to its pulverulent form, which deprives other metals of that property, though they decidedly possess it when in mass.

Heated to redness in the air, it takes fire, and burns with great brilliancy into white and tolerably hard alumina. When projected on the flame of a candle, it emits sparks as brilliant as those of iron burning in oxygen gas. It burns in oxygen gas with a splendour which the eye can hardly support, and with so much heat that the resulting alumina is, in part at least, fused into yellow fragments, which are as hard as corundum, and not only scratch, but absolutely cut glass. It is remarkable, that to occasion combustion, even in oxygen, the aluminum must be introduced red-hot.

Aluminum is scarcely acted upon by water, and water may be evaporated from it, at low temperatures, without diminishing its metallic aspect. Even boiling water produces only a slow and indistinct effect. At common temperatures, it is not altered by concentrated sulphuric or nitric acid; but in the first, when heated, it dissolves rapidly, with an escape of sulphurous acid. In diluted sulphuric and muriatic acids it dissolves with a disengagement of hydrogen, and the same effect is produced by weak solutions of potassa. Even ammonia dissolves it, and in very large quantity.

When ignited in a current of chlorine, it takes fire, and is changed into chloride of aluminum, which the heat volatilizes.

It unites with sulphur, phosphorus, selenium, arsenic, and tellurium, generally with incandescence.

Such are the properties of aluminum, now first unfolded to us in a distinct form by Wöhler, who must be allowed to share with Davy and Oersted in the credit of its discovery.

Alumina.

Alumina may be obtained free from other earths, but still combined with carbonic acid, by precipitating a solution of alum in water by the bi-carbonate of potassa. To secure its complete purification from sulphuric acid, Guyton advises that the precipitate be re-dissolved in nitric acid, that nitrate of baryta be cautiously added to the solution, till it no longer occasions milkiness, and that the alumina be afterwards precipitated, or separated from the nitric acid by heat. (Ann. de Chim. xxxii. 64.) Electro-chemical analysis, however, in this, as in many other instances, shows the imperfection of the common methods of separating bodies from each other; for the most carefully prepared alumina yields the metals of soda and potassa, when negatively electrified in contact with mercury. (Davy, Phil. Trans. 1808.) Berzelius, also, found that when alumina is precipitated either from the sulphate or nitrate, it is contaminated with those acids; but not with the muriatic, when thrown down from the muriate of alumina by ammonia. Gay Lussac recommends the preparation of alumina by exposing that kind of alum which has ammonia for its base, first to a gentle heat to expel the water of crystallization, and afterwards to a red heat, which leaves the alumina pure. (Ann. de Ch. et de Ph. v. 101.)

Alumina has the following properties:

1. It is destitute of taste and smell.

2. When moistened with water, it forms a cohesive and ductile mass, susceptible of being kneaded into a regular shape. It is not soluble in water; but retains a considerable quantity, and is, indeed, a hydrate, containing, when dried at the temperature of the atmosphere, almost half its weight of water. Even after ignition, alumina has such an affinity for moisture, that it can hardly be placed on the scale of a balance without acquiring weight. Berzelius found that 100 parts, after being ignited, gained 15¼ from a dry atmosphere, and 33 from a humid one. For full saturation, 100 grains of alumina, he ascertained, require 54 of water. (82 Ann. de Ch. 14.) Dr. Thomson, from 100 grains of precipitated alumina, left to dry on a filter during two months at a temperature not exceeding 60° Fahr., expelled by a red heat 51.30 grains of water; hence the hydrate thus obtained was constituted very nearly of equal weights of alumina and water.

3. Alumina does not affect blue vegetable colours.

4. It is dissolved by the liquid fixed alkalies, and is precipitated unchanged by acids. In ammonia, it is very sparingly soluble. It is not soluble in alkaline carbonates.

5. Baryta and strontia combine with alumina, both by fusion and in the humid way. In the first case, the result is a greenish or bluish coloured mass. In the second, two compounds are formed. The first, containing an excess of alumina, is in the state of an insoluble powder; the other, having an excess of the alkaline earth, remains in solution. Alumina may be united, by fusion, with the fixed alkalies, and with most of the earths.

6. Alumina, as will be afterwards shown, has a strong affinity for colouring matter.

7. Alumina has the property of shrinking considerably in bulk, when exposed to heat, and its contraction is in proportion to the intensity of the heat applied. On this property is founded the *pyrometer of Wedgwood*, which measures high degrees of heat, by the amount of the contraction of regularly shaped pieces of china clay. The pieces of clay are small cylinders, half an inch in diameter, flattened on the under surface, and baked in a low red heat. The contraction of these pieces is measured, by putting them between two fixed rulers of brass or porcelain, twenty-four inches long, half an inch distant from each other at one end, and three-tenths of an inch at the other. The rulers are divided into 240 equal parts, called degrees, which commence at the wider end; and each of which is equal to 130° of Fahrenheit. When the clay piece is fixed in its place, before exposure to heat, it is stationary at the first degree, which indicates about 1077° of Fahrenheit. After being strongly heated, in a small case which defends it from the fuel, its bulk is diminished, and it slides down, between the converging rulers, till stopped by their approach. The number on the graduated scale, opposite to the upper end of the piece, indicates the degree of heat to which it has been exposed. In the Appendix, rules may be found for reducing the degrees of Wedgwood's pyrometer to those of Fahrenheit's thermometer. It is proper, however, to

remark, that this instrument is a much less accurate measurer of heat than was long supposed; since the contraction of clay is influenced not merely by the degree of heat to which it is exposed, but by the mode of its application.

Alumina forms a very large proportion of the rocks and strata that compose this globe. It is the chief ingredient of all the varieties of clay, and gives them the property of tenacity and ductility, or of being capable of being moulded into the shapes of vessels, which are rendered hard and durable by the subsequent application of heat. Bricks, tiles, and all the varieties of pottery and porcelain, are chiefly formed of alumina, with variable proportions of silica and other earths. It imparts to soils, when present in due proportion, the quality of being sufficiently retentive of moisture; for a soil may be too open and light to be fertile, as well as too stiff from the excess of its aluminous ingredient. It is remarkable, also, that alumina, nearly pure, composes some of the hardest minerals, such as the corundum, which is hard enough to be employed in polishing diamonds.

Equivalent of Alumina.

The equivalent number, or weight of the atom, of alumina, has been less satisfactorily determined than that of most of the earths. It was probably from the uncertainty which he found to exist respecting the analysis of its compounds, that Dr. Wollaston did not include alumina, or its salts, among the examples selected to illustrate the principle of his scale of equivalents. From indirect experiments, Sir H. Davy, several years ago, derived 24 as the number representing alumina, and, by analogy, 16 for that of aluminum. Dr. Thomson, from a careful analysis of alum, deduced 18 as the atomic weight of alumina (Ann. of Phil. N. S. iii. 168), a number very nearly agreeing with that assigned by Gay Lussac, and answering to 17.28, hydrogen being 1. From an investigation arising out of the analysis of a peculiar species of sulphate of alumina, Mr. R. Phillips concluded that the atomic weight of that earth is more correctly represented by 27. (Ann. of Phil. N. S. iv. 283.) This opinion has induced Dr. Thomson again to examine the subject, by comparing the results of the best analyses of various compounds of alumina, and by carefully repeating the analysis of alum. (First Princ. i. 285.) The result of this inquiry has been to strengthen his conviction, that the relative weight of the atom of alumina is correctly represented by 18; from which number, if we deduct 8 (an atom of oxygen), we obtain 10 for the equivalent of aluminum. This number, it may be observed, agrees with Berzelius's account of the saturated hydrate of alumina, as nearly as can be expected, if we consider the difficulty of obtaining hydrates with exactly the proportion of water essential to their chemical constitution; for if 100 parts of alumina combine with 50 of water to form that hydrate, it will consist of an atom of alumine = 18, and an atom of water = 9. The hydrate, described by the same authority, with 15½ of water to 100 of earth, will be found not very remote from 1 atom of water to 3 of alumina, and that with 33 of water to 100 earth corresponds very nearly with 2 atoms of water (18) to 3 of alumina (54). The hydrate described by Dr. Thomson, composed of equal weights of water and base, must of course, if the atom of alumine be just double that of water, be a bi-hydrate. The probability that 18 is the true atomic weight of alumina, will be confirmed by the analysis of some of its salts.

Salts of Alumina.

Alumina with chlorine.—No substance (Sir H. Davy observes) exists, that can be considered as a true compound of alumina and chlorine.

Muriate of alumina may be formed by dissolving fresh precipitated alumina in muriatic acid, but the acid is always in excess. It is scarcely possible to obtain this salt in crystals, for by evaporation it becomes a thick jelly. It is extremely soluble in water, and when dried deliquiates. At a high temperature it abandons its acid.

Nitrate of alumina may be formed in the same manner as the last-mentioned compound. The solution, which is always acid, crystallizes in thin ductile plates. The crystals are extremely soluble, and are deliquescent. When dried by pressure between folds of blotting-paper, Dr Thomson finds them to consist of 1 atom of nitric acid, 2 atoms of base, and 10 of water. By a stronger heat it loses a portion of its acid.

Alum.—Sulphate of Alumina.

Alum and sulphate of alumina are often confounded together under the same name; but alum, as will afterwards appear, is not a mere combination of this earth with sulphuric acid; but is a triple salt, composed either of sulphuric acid, alumina, and potassa; or of sulphuric acid, alumina, and some other base. It has the following characters:

(*a*) It has a sweetish astringent taste. Its specific gravity is 1.71. Its crystals are regular octahedrons, often of great size and beauty.

(*b*) It dissolves in water, five parts of which, at 60°, take up one of the salt, but hot water dissolves about three-fourths of its weight.

(*c*) This solution reddens the blue colour of litmus decidedly, and that of tincture of cabbage slightly; but blue tinctures from the petals of plants are generally turned by it green. (Quart. Journ. xviii. 396.)

(*d*) When mixed with a solution of carbonate of potassa, an effervescence is produced, and the first portions of alkali, that are added to a solution of sulphate of alumina, do not occasion any precipitate. On a farther addition of alkali, the alumina is precipitated, in combination with carbonic acid. The presence of organic substances, according to Rose, prevents the precipitation of alumine in small quantity from acids. (34 Ann. de Ch. et de Ph. 272.)

(*e*) Alum, when heated, swells up, loses its regular form, and becomes a dry spongy mass, called burnt alum. If the heat be considerable, it loses part of its acid; but, according to Vauquelin, the whole of its acid cannot be thus expelled.

(*f*) Alum is decomposed by charcoal at a red heat, and the product is the *pyrophorus of Homberg*. To prepare this, equal parts of powdered alum and brown sugar are melted over the fire, and are kept stirring till reduced to dryness. The mixture, when cold, is to be finely powdered, and introduced into a common phial, coated with clay, to which a glass tube, open at each end, is to be luted, to allow the escape of the gases that are produced. The phial must then be set in the fire, surrounded by sand, in a crucible. Gas will issue from the open end of the tube, and may be inflamed by a lighted paper. When this ceases to escape, the crucible may be removed from the fire, and a little moist clay pressed down upon the open end of the tube, to prevent the access of air to the contents of the phial. When cold, the tube may be removed, and a cork substituted in its place. The principal difficulty in the process is to stop it precisely at the period when the pyrophorus is formed; for, if the heat be continued longer, the preparation will be spoiled.

Gay Lussac, in preparing pyrophorus, substitutes lamp-black with great advantage. During its formation in a stone-ware retort, he obtained products which show that the combustible residue is in part a sulphuret of potassium with several atoms of sulphur. No excess of potassium exists in it, for the pyrophorus thus obtained, though highly inflammable in air, with an evolution of sulphurous acid, does not decompose water. Sulphate of magnesia he finds may be substituted for alum. But the most combustible compound of this kind, ever procured, was obtained by calcining an intimate mixture of 15 parts of lamp-black with 27.3 parts of sulphate of potassa. Unlike common pyrophorus, this species does not require a humid atmosphere to set it on fire, nor does it give sulphurous acid in burning; but it agrees with the common kind in not decomposing water. This last character proves the absence of uncombined potassium, of which metal, in the state of a sulphuret, diffused through finely divided sulphur, the new pyrophorus appears to consist. Sulphate of soda, freed from water, may be substituted for sulphate of potassa. (Ann. de Ch. et de Ph. April, 1828.)

Composition of alum.—Considerable differences exist in the statements which have been given by different analysts of the composition of alum, as will appear from the following table:

100 parts contain	Acid.	Alumina.	Potassa.	Water.
According to Vauquelin - -	30.52	10.50	10.40	48.58
——————— Dalton - - -	33.	12.	9.	46.
——————— R. Phillips - -	34.94	11.18	10.33	43.55
——————— Berzelius - -	34.23	10.86	9.81	46.
Do. corrected by Thomson -	33.82	10.86	9.90	45.
——————— Dr. Thomson -	32.80	11.	9.80	46.4

Some of these differences may be accounted for by the circumstance, that in calculating the sulphuric acid, the composition of sulphate of baryta has been stated differently. When well edulcorated, dried, and ignited, the barytic sulphate has been estimated to contain, in every 100 grains, 33.9 grains of real sulphuric acid; but these numbers are to be regarded as provisional. (See p. 510.)

Different views also have been taken of the state of combination in which the potassa and sulphuric acid exist in alum. Mr. R. Phillips considers the constitution of crystallized alum to be as follows, a slight alteration of his experimental results being made to accommodate them to atomic proportions, and the atom of alumina being taken at 27.

1 atom of bi-sulphate of potassa - - -	128
2 atoms of sulphate of alumina (67 × 2)	134
25 atoms of water (9 × 25) - - - - -	225
Weight of its atom,	487

Dr. Thomson, however, does not admit that bi-sulphate of potassa exists in alum, and contends that it is constituted of

1 atom of sulphate of potassa - - - -	88
3 atoms of sulphate of alumina (58 × 3) -	174
25 atoms of water (9 × 25) - - - - -	225
Weight of its atom -	487

It is obvious that the atomic weight of the crystals is the same, whether we consider alum as containing *sulphate* or *bi-sulphate* of potassa, the theoretical view of its constitution depending entirely on the atomic weight which we assign to alumina. Now the question, whether the equivalent of alumina be 18 or 27, must be settled by taking into view the compounds which that base forms with other substances, and it has been already shown that the composition of the hydrates agrees best with the opinion that 18 is the true number. To this evidence may be added that which Dr. Thomson has derived in favour of the same atomic weight, from examining analyses, which have been made by other persons, of a great variety of crystallized minerals. (First Princ. of Chem. i. 288.)

Ammoniacal alum has been examined by Riffault, (Ann. de Chim. et de Phys. ix. 106), who found it to consist of

1 atom of sulphate of ammonia,
3 atoms of sulphate of alumina,
24 atoms of water.

In this species of alum, M. Riffault concludes that 11.906 of alumina are united with 26.979 of sulphuric acid, the remaining 9.063 of the acid being combined with 3.898 of ammonia.

In the Quarterly Journal (viii. 386) an alum containing *soda* as its alkaline base, is described. It appears to be constituted of 51.2 water, 32.14 sulphuric acid, 10 alumina, and 6.32 soda, or of

2 atoms of sulphate of alumina,
1 atom of bi-sulphate of soda,
28 atoms of water.

In vol. xiii. p. 276 of the same journal, Dr. Ure assigns nearly the same proportions to a soda alum examined by him.

Magnesia, also, it appears, is capable of furnishing a base to alum; but, like the last species, it has not yet been applied to any useful purpose.

A neutral sulphate of alumina was obtained by Berzelius by the following process:—He decomposed alum by ammonia; washed the precipitate, and redissolved it in sulphuric acid. To the liquor, after evaporation, he added alcohol, which threw down a sulphate nearly neutral, and rendered perfectly so, by being washed with farther portions of alcohol. Gay Lussac has also given the following process, communicated to him by Descostils, for preparing a neutral sulphate of alumina. On alum with base of ammonia, boil nitro-muriatic acid till all the ammonia is destroyed, and evaporate to dryness to expel all the nitric and muriatic acids. The ammonia is decomposed by the chlorine, which results from the mutual action of those two acids, and the alumina remains in combination with sulphuric acid only. The saturated solution of this salt in water is an excellent test to discover potassa; for a drop or two, added to a solution of that alkali, or of any of its salts, immediately causes a precipitation of alum. (Ann. de Chim. et de Phys. vi. 201.) It most probably consists of 1 atom of acid + 1 atom of base. This appears, also, to be the constitution of the native sulphate from Saldana, described by Boussingault, in which the sulphuric acid is to be the base as 1.82 to 0.80, or as 40 to 18 very nearly. (Ann. de Ch. et de Ph. xxx. 110.)

The subsulphate of alumina and potassa, obtained by pouring potassa into a boiling hot solution of alum, formerly called *alum saturated with its earth*, has been analyzed by M. Riffault, (Ann. de Ch. et de Phys. xvi. 355), and found to consist of

Sulphuric acid - - - - - -	36.187
Alumina - - - - - - - - -	35.165
Potassa - - - - - - - - - -	10.824
Water - - - - - - - - - -	17.824
	100.

Now of the sulphuric acid, 9.02 parts must have been engaged by the potassa, leaving 27.167 parts of acid united with 35.165 of alumina, a proportion agreeing so very nearly with that of 40 to 54, that we can have little hesitation in admitting an atom of sulphuric acid (40) to be combined with 3 atoms ($18 \times 3 = 54$) of base. The native subsulphate or *aluminite*, found by Stromeyer to contain 30 acid, 24 base, and 45 water, approaches also very closely to the same atomic constitution. We have, therefore, two combinations of sulphuric acid and alumina distinctly made out, viz.

	At. of Acid.		At. of Base.
The sulphate existing in alum -	1	+	1
Subtrisulphate - - - - - - -	1	+	3

To these Dr. Thomson (lib. cit. i. 313) adds a third, consisting of 1 atom of acid + 2 of alumina, which he calls a *disulphate*, but he has not described any process by which it may with certainty be obtained.

The remaining salts of alumina have no properties sufficiently important to entitle them to a separate description, with the exception of a few, which will be mentioned hereafter.

SECTION XI.

Zirconium.

The base of zirconia, or *zirconium*, was investigated by Sir H. Davy in the same manner as the bases of other earths. When potassium was brought into contact with ignited zirconia, potassa was formed, and dark metallic particles were diffused through the alkali.

Berzelius obtains zirconium by a process analogous to that which he uses in decomposing silica. When thus procured, it is as black as charcoal; is not oxidized either by water or muriatic acid, but aqua regia and fluoric acid both dissolve it, the latter with a disengagement of hydrogen. At a slightly elevated temperature, it burns with extreme intensity. It combines with sulphur, forming a chesnut brown sulphuret, which is insoluble in muriatic acid and in alkalies, and burns brilliantly, forming sulphurous acid and zirconia. (Ann. of Phil. N. S. viii. 123.)

Zirconia.

I. This earth was discovered by Klaproth, in the year 1789, in a precious stone from the island of Ceylon, called Jargon or Zircon, and has since been detected in the Hyacinth.

MM. Dubois and Silveira have described the method of obtaining zirconia from zircons as follows:—Powder the zircons very fine, mix them with two parts of pure potassa, and heat them red hot in a silver crucible for an hour. Treat the substance obtained with distilled water, pour it on a filter, and wash the insoluble part well; it will be a compound of zirconia, silica, potassa, and oxide of iron. Dissolve it in muriatic acid, and evaporate to dryness, to separate the silica. Re-dissolve the muriates of zirconia and iron in water; and to separate the zirconia which adheres to the silica, wash it with weak muriatic acid, and add it to the solution. Filter the fluid, and precipitate the zirconia and iron by pure ammonia; wash the precipitates well, and then treat the hydrates with oxalic acid, boiling them well together, that the acid may act on the iron, retaining it in solution while an insoluble oxalate of zirconia is formed. It is then to be filtered, and the oxalate washed, until no iron can be detected in the water which passes through. The earthy oxalate is, when dry, of an opaline colour; after being well washed, it is to be decomposed by heat in a platinum crucible.

Berzelius separates oxide of iron from zirconia, by precipitating a neutral solution of zirconia with liquid sulphate of potassa. The oxide of iron remains dissolved. The same object may be attained by more complicated methods, which he has described in an elaborate memoir on this earth. (Ann. de Ch. et de Ph. xxix. 337.)

When thus obtained, zirconia is perfectly pure, but is not soluble by acids. To render it so, it must be re-acted on by potassa as before, and then washed until the alkali is removed. Afterwards dissolve it in muriatic acid, and precipitate by ammonia. The hydrate thrown down, when well washed, is perfectly pure, and easily soluble in acids. (Ann. of Phil. New Series, i. 74.)

II. Zirconia has the following properties:

1. It has the form of a fine white powder, which, when rubbed between the fingers, has somewhat of the harsh feel of silica. It is entirely destitute of taste and smell. Its specific gravity exceeds 4.

2. It is insoluble in water; yet it appears to have some affinity for that fluid, for it retains, when slowly dried after precipitation, one-third its weight, and assumes a yellow colour and slight transparency, like that of gum arabic. The hydrate was found by Berzelius to contain,

Zirconia - - - - - - - -	87.11
Water - - - - - - - - - -	12.89
	100.

3. It is insoluble in pure liquid alkalies; nor does it even combine with them by fusion. It is soluble in alkaline carbonates; but, according to Berzelius, not easily or perfectly in that of ammonia.

4. Exposed to a strong heat, zirconia fuses, assumes a light grey colour, and such hardness, on cooling, as to strike fire with steel, and to scratch glass, or even rock crystal.

5. Its action on other earths has not been fully investigated.

6. It dissolves readily in acids. Its solution in muriatic acid, when sufficiently heated, becomes milk white, and runs in some measure into a jelly, especially if concentrated to a certain point by evaporation.

7. From the muriatic solution of zirconia, oxalic acid throws down a white precipitate, which is re-dissolved by an excess of the acid.

8. It is precipitated from its acid solutions, by the neutral succinates and benzoates, in copious white bulky flocks, which are again readily dissolved by an excess of succinic acid. It is also thrown down from its solutions by tartaric acid, malic acid, and tartrate of potassa.

9. From a sufficiently neutral solution of zirconia, ferro-cyanate of potassa throws down a greenish blue precipitate, which, on adding muriatic acid, becomes more blue, but after some time changes into celadon green.

10. Hydrosulphuret of ammonia produces, in the muriatic solution of zirconia, a dark olive or blackish green precipitate in very loose flocks. This precipitate may be washed with water without changing colour; but, when exposed to sunshine, it becomes white.

Professor Pfaff has remarked, that in most of their properties there is a striking resemblance between zirconia and oxide of titanium. The only re-agent, which acts in a strikingly different manner upon solutions of oxide of titanium and zirconia, is tincture of galls, which, from the common solution of oxide of titanium, throws down a reddish brown precipitate, whereas from solution of zirconia it occasions a deposition of yellow flocks. (Ann. of Phil. xiii. 88.)

We have as yet no good data for calculating the atomic weight of zirconia, but Dr. Thomson considers it probable, from some experiments of his own, that it is 48. (First Princ. i. 335.) Berzelius considers zirconia as constituted of

Zirconium - - -	73.686 - - -	100.
Oxygen - - - -	26.314 - - -	35.697
	100.	

This would give the proportion of oxygen to the metallic base as 8 to 22.32. (An. de Ch. et Ph. xxix. 337.)

SECTION XII.

Silicium.

In his attempts to obtain the base of silica, or *silicium*, in a state of perfect separation, Sir H. Davy was unsuccessful; but the results of his experiments left no room to doubt that this earth is, like the rest, compounded of oxygen with a peculiar base. Berzelius afterwards decomposed silica, by fusing it with charcoal and iron in a blast furnace. He obtained an alloy of iron and *silicium*, which, by the action of a diluted acid, gave more hydrogen than the same weight of iron. (81 Ann. Ch. 179; see also his account of an attempt to analyze silica, in 40 Phil. Mag. 201.) This process was successfully repeated by Stromeyer, and the properties of the different alloys investigated. He recommends the fusion of 7 parts of iron, 5 of silica, and from $\frac{1}{4}$th to $\frac{8}{10}$ths of a part of soot. From the results of acting on the alloy by dilute acids, Berzelius infers silica to consist of

Silicium - - - -	45.92 - - -	100.
Oxygen - - - -	54.08 - - -	117.38
	100.	217.38

In attempting to reduce fluoric acid by potassium, Berzelius succeeded in decomposing silica, and obtaining silicium in an insulated state. (Ann. de Ch. et de Phys. xxvii. 337.) Potassium, carefully purified by distillation, when burned in silicated fluoric acid gas, condenses it, and a brown substance is separated, which, after being boiled in water and dried, burns in oxygen gas, producing no carbonic acid, but yielding silicated fluoric acid and silica. The residue of the combustion, treated with fluoric acid, gave silicated fluoric acid, and its colour was rendered much darker. Thrown on a filter, washed, and dried, it was pure silicium, which may be obtained, also, by heating potassium in a glass tube with dry silicated fluate of potassa. The product, by being well washed with water, yields a compound of silicium and hydrogen, from which the latter may be detached by heating in a crucible.

Pure silicium is incombustible, even in oxygen gas. It is not attacked by water, aqua regia, sulphuric or nitric acid, nor by caustic potassa; but fluoric acid, especially with the addition of a little nitric acid, has a solvent action on it. When heated with nitre, if a small fragment of dry carbonate of soda be plunged into the mixture, detonation immediately ensues. When the vapour of sulphur is brought into contact with ignited silicium, the latter suddenly becomes incandescent. The resulting sulphuret decomposes water with extreme rapidity; sulphureted hydrogen is evolved; and the water dissolves so much of the newly regenerated silica, that it thickens and coagulates during evaporation, and lets fall a gummy transparent mass.

In chlorine gas, silicium takes fire at a red heat, and a slightly yellow liquid is formed, with an odour resembling that of cyanogen, extremely volatile, and when water is added, setting and depositing gelatinous silica. Oersted has obtained chloride of silicium by exposing a heated mixture of silica and charcoal to chlorine, the excess of which he removed by mercury and subsequent distillation. In this way he obtained a transparent fluid, having the aspect of sulphuric ether, and which boiled under 212° Fahr. (Ann. de Ch. et de Ph.)

When heated with carbonate of potassa, silicium exhibits a brilliant inflammation, and carbonic acid is evolved. With the hydrates of the fixed alkalies, it detonates and produces a vivid incandescence at a temperature below redness. Nitrate of potassa acts upon it only after the destruction of the nitric acid by heat.

Silicium is a non-conductor of electricity. It does not, when once reduced, combine easily with other metals, though silica, reduced along with other metals, readily yields alloys of silicium.

The base of silica has been considered by Sir H. Davy and by Dr. Thomson, as offering a closer analogy with boron and carbon than with metals, and hence they have chosen to call it *silicon.* Berzelius, however, with whom I am disposed to agree, does not coincide in this view of its nature, and still continues to give it the name of *silicium.* From synthetical experiments, 48 parts unite with 52 of oxygen. Supposing the elements of silica to be in equal weights, the same number would represent silicium and oxygen; and that this is its true atomic weight, Dr. Thomson is induced to believe, by an examination of various compounds of silica, the equivalent number of which, supposing it to consist of an atom of base and an atom of oxygen, will be 16.

Silica.

I. Siliceous earth, or silica, may be obtained tolerably pure by the following process:—Procure some common gun-flints, and calcine them in a crucible in a low red heat. By this treatment they will become brittle, and easily reducible to powder. Mix them, when pulverized, with three or four times their weight of carbonate of potassa, and let the mixture be fused in a strong red heat, in a crucible. The materials must bear only a small proportion to the capacity of the crucible; and the heat must at first be very moderate, and slowly increased. Even with this precaution, the mass, on entering into fusion, will be apt to overflow; and must be pressed down as it rises, by an iron rod. When this effervescence has ceased, let the heat be considerably raised, so that the materials may be in perfect fusion during half an hour, and pour the melted mass on a copper or iron dish. We shall thus obtain a compound of alkali and siliceous earth. Dissolve this in water, filter the solution, and pour it into diluted sulphuric or muriatic acid. An immediate precipitation will ensue, and, as long as this continues, add fresh portions of the solution. In precipitating the alkaline solution of silica, more acid must be used than is sufficient to engage the alkali; and the alkaline liquor must be added to the acid, and not the reverse; for, in the latter case the precipitate will be glass, and not silica. Let the precipitate subside, pour off the liquor that floats above it, and wash the sediment with hot water, till it comes off tasteless. Then dry it. (See also Faraday's Chem. Manip. § 164.)

Silica, obtained by this process, though pure enough for the following experiments, may still contain a portion of alumina. To separate the latter earth, boil the precipitate with diluted sulphuric acid, to which a little sulphate of potassa may be added. The alumina will thus be dissolved; and, the silica may be freed from the solution of alum by repeated washings with water. Even silica, however, that has been most carefully washed, still gives traces of potassa on the application of electro-chemical powers. (Davy.) According to Mr. Brande, silica may be obtained of sufficient purity for most purposes, by heating rock-crystal to redness, quenching it in water, and then reducing it to fine powder.

II. Siliceous earth, as thus obtained, has the following qualities:

(*a*) It is perfectly white and tasteless. It is infusible by the intense heat of Voltaic electricity; (Phil. Trans. 1815, p. 370;) but was melted by Dr. Clarke with the oxygen and hydrogen blow-pipe. To a certain degree it appears to be volatile, for a filamentous substance, collected from iron furnaces, and resembling amianthus, was found by Vauquelin to be pure silica.

(*b*) When mixed with water, it does not form a cohesive mass like alumina, but has a dry and harsh feel to the fingers. It retains, when fresh precipitated, about 26 per cent. of water, after being dried at 70° Fahr. According to Berzelius, this water is not chemically combined; but Dr. Thomson describes several hydrates of silica, in which the water is present in atomic proportion.

(*c*) It is insoluble in water. Yet when fresh precipitated, water has the property of retaining in solution about one thousandth of its weight. (See Klaproth's Contributions, i. 399, 400.) That silica, however, is dissolved in water by processes of nature, can scarcely be doubted, when it is considered, that it is found in considerable quantities, in a crystallized form. Its extreme solubility, when newly formed, is established by the observation of Berzelius already cited.

(*d*) It is not considerably acted on by any acid, except the fluoric, but most acids, even the carbonic, dissolve a minute quantity. (Karsten in Jameson's Journ. Jan.-March 1827, p. 392.) Sulphuric acid, according to Dalton, after expelling the fluoric acid from fluate of lime, does not unite with the silica. But though the earth itself is scarcely dissolved by acids, yet when first combined with an alkali, it unites with several acids, forming triple salts. (81 Ann. de Chim. 239.) When fresh precipitated, however, it is sparingly soluble in most acids; and, for this reason, Dr. Marcet advises, in analysis, to precipitate silica by muriate of ammonia, which does not, like the acids, redissolve it.

(*e*) When prepared in the foregoing manner, and very minutely divided, silica is taken up by a solution of pure potassa, or of soda, but not by ammonia. In the aggregated state of flints, however, it is perfectly insoluble in this way by alkaline solutions; an excellent illustration of the principle, that a very minute division of solid bodies, by presenting a greater surface to the action of fluids, facilitates solution.

(*f*) When mixed with an equal weight of carbonate of potassa, and exposed to a strong heat in a furnace, it forms a glass, insoluble in water, and identical in all its properties with the glass commonly manufactured. It is owing to the siliceous earth which it contains, that glass is decomposed by the fluoric acid. Glass, however, has occasionally other ingredients, besides the two that have been mentioned, the object of which admixtures is to adapt it to particular purposes. *Flint glass* is formed of fine siliceous sand, pearlash, litharge, or minium, a little nitre, and a small quantity of manganese; *crown glass for windows*, of soda, fine siliceous sand, lime, and fragments of glass; *green bottle glass*, of sand, kelp, pearlash, clay, and fragments of glass; and *plate glass*, of fine sand, soda, lime, manganese, oxide of cobalt, and fragments of glass. *Pastes or artificial gems*, are only another variety of glass, into the composition of which borax generally enters, the colour being given by various metallic oxides.*

(*g*) With a larger proportion of potash, as three or four parts to one of silica, this earth affords a compound, called, by Dr. Black, *silicated potassa*. This compound, formed by the process which has been just described, is soluble in water, affording a solution which was formerly termed *liquor silicum*, or *liquor of flints*. Acids seize the alkali, and precipitate the silica, which is even separated by mere exposure to the atmosphere, in consequence of the absorption of carbonic acid by the alkali.

A boiling solution of caustic soda readily dissolves pure precipitated silica, even when dried, but the solution, when fully charged with silica, continues to act on test colours like an alkali. By evaporation and drying at 242°, a pale yellowish mass remains, of a perfect glossy transparency, consisting probably of 1 atom of soda, 8 of silica, and 13 or 14 atoms of water. It is deliquescent and soluble in water; and the solution, if not too dilute, is gelatinized by adding a quantity of acid precisely equivalent to the soda. If the smallest excess of acid be present, the silica is not precipitated. (Walcker, in Quart. Journ. N. S. iii. 372.)

(*h*) Baryta or strontia, and silica, combine together, in a manner similar to the union of this earth with alkalies; but the combination has not been applied to any useful purpose.

(*i*) When a solution of silica in potassa is mingled with one of baryta, of strontia, or of lime in water, or of alumina in alkali, a precipitation ensues. Hence silica may be inferred to have an affinity for all these earths, in the humid way. The composition of these precipitates is stated by Mr. Dalton, in his New System, p. 541.

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* See Guyton, Ann. de Chim. vol. lxxiii. and Aikin's Dictionary of Chemistry, art. Glass, for an excellent account of the several varieties of glass.

In consequence of its possessing a stronger affinity for alkalies and earths than for acids, as well as from its other habitudes, silica has been thought to present a closer analogy with acids than with earths, and in a chemical arrangement to be more properly placed in the former class than in the latter. On the other hand, as it is deficient in some of the characters which have hitherto been deemed essential to acidity, I have not thought it expedient to remove it from the place which it has generally held in chemical arrangements.

Silica is a very abundant product of nature. It constitutes a principal ingredient of several rocks that form extensive mountain masses, such as granite; it composes a large proportion of the sand found in the beds of rivers, and on the sea shore; and it enters largely into several minerals of rarer occurrence, as rock-crystal, quartz, flint, chalcedony, cornelian, opal, &c. It constitutes an essential ingredient of fertile soils, and renders them porous and open to the transmission of moisture. In the arts, its most important application is to the manufacture of glass, and a certain proportion is of use in the composition of porcelain; for absolutely pure clay, without an admixture of siliceous earth, would shrink too much to be fit for the uses of the potter.

Silicated Fluoric Acid, or Fluo-silicic Acid.

Fluo-silicic acid gas may be prepared by pouring on finely powdered fluor spar, mixed with half its weight of pulverized glass, an equal weight of strong sulphuric acid. The gas may be received over mercury in glass vessels, the transparency of which it does not impair.

1. The specific gravity of this gas is very high, *viz.* 3.573 or 3.61, (3.60 Dumas); 100 cubic inches of it weighing 110.78 grains. By causing a known volume of it to be absorbed by liquid ammonia, Dr. John Davy separated the silica, which he found to weigh 61.4 per cent. of the weight of the gas. Dr. Thomson, from 40 cubic inches (= 44.05 grains) obtained 27.14 grains of silica. Hence we may conclude that fluo-silicic acid is a compound of

Fluoric acid - - - - 1 atom = 10
Silica - - - - - - - 1 atom = 16

Weight of its atom - - 26

Berzelius, however, considers it as consisting of 3 atoms of acid + 2 atoms of silica.

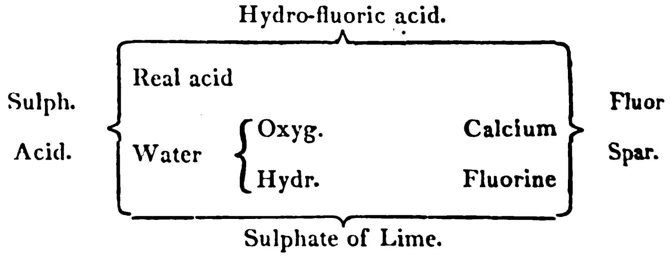
2. Water absorbs about 263 times its volume of the gas, and the solution may be kept in glass vessels without corroding them. During its absorption it deposits silica, and retains in combination only 54.5 per cent. This liquid Dr. Davy calls *sub-silicated fluoric acid.*

3. The gas condenses twice its volume, and no other proportion,

of ammoniacal gas, forming a dry white salt, which is slightly acid, deposits silica by solution in water, and, when its concentrated solution is boiled in glass vessels, powerfully corrodes them. By adding an excess of liquid ammonia, the whole of the silica is precipitated, and a pure fluate of ammonia is obtained.

4. The effects of heating potassium in silici-fluoric gas have already been described in the section on Silicium.

Fluo-silicic acid unites with several bases, and forms compounds which have been investigated by Berzelius. These he is of opinion have been improperly called *fluo-silicates*, because fluo-silicic acid is, he conceives, not an acid with a double base of which silica is one element, but *a hydro-fluate of silica*, capable of existing in the gaseous state. The reader who attentively considers this view, will find it perfectly consistent with the opinion that fluor spar may be a *fluoride of calcium*, as suggested at page 254. In that case we may conceive the changes, that take place in the formation of the gas, to be as follows:—An atom of sulphuric acid, = 1 atom real acid, + 1 atom of water, acts upon 1 atom of fluor spar = 1 atom fluorine + 1 atom calcium. The atom of water is decomposed; its oxygen, uniting with the calcium, forms lime, which combines with the redundant sulphuric acid; its hydrogen, with the disengaged atom of fluorine, forms hydro-fluoric acid, which, while in a nascent state, unites with silica, and composes the peculiar gas. This view, hypothetical as it certainly is, appears to me more probable than the supposition that the gas is a compound of fluorine and silicium; for any person, who will attend to the following diagram, will see that the phenomena are sufficiently explained, without supposing the decomposition of silica into its elements.



The generic and specific characters of the fluo-silicates are fully described in the memoir by Berzelius, which may be found in the 27th vol. of Ann. de Chim. et de Phys. or in the 8th vol. N. S. of Annals of Philosophy.

Fluo-silicic acid unites with iodine, when the vapours of both substances are brought into contact. The addition of water causes a precipitation of silica, and the whole of that earth is thrown down by ammonia. The liquid, which is at first alkaline, on being heated becomes acid, and being filtered and cooled deposits small crystals of a fine golden yellow colour. To these, Varvinsky, who discovered them, has given the name of *iodo-fluoric acid*. (Quart. Journ. N. S. iii. 224.)

APPENDIX.

DESCRIPTION OF THE COPPER PLATES.

[*To facilitate the reference to the Plates, they are placed at the end of Vol. II.*]

PLATE I.

FIG. 1. (*a*) *A plain retort*, the neck of which is shown introduced a proper length into the mouth of a *plain receiver*, *b*. These may be made of any size, from the capacity of a few drachms to that of several gallons, and either of white or green glass. The latter material has the advantage, when solids are distilled, of being much less fusible than flint glass.

FIG. 2. *A glass alembic; a* the body, and *b* the head, which are ground so as to fit accurately, and may be separated when necessary. The head *b* is so shaped, that any liquid, which may be condensed, collects into a channel, and is carried by the pipe *c* into the receiver.

FIG. 3. *A separator*, for separating liquids of different specific gravities. It is furnished with a ground stopper at *a*, and a glass stop-cock at *b*. The vessel is filled with the liquids that are to be separated (oil and water, for example), which are allowed to stand till the lighter has completely risen to the top. The stopper *a* is then removed, and the cock *b* opened, through which the heavier liquid descends; the cock being shut, as soon as the lighter one is about to flow out.

FIG. 4. A glass vessel, termed a *matrass*, useful for effecting the solution of bodies, which require heat before they can be dissolved, or long continued digestion. The upper extremity of the long neck generally remains cool, and allows the vessel and its contents to be shaken occasionally.

FIG. 5. A glass bottle with a very thin bottom, and a projecting ring round the neck for suspending it over a lamp. These are useful for effecting *solutions* on a small scale.

FIG. 6. An apparatus contrived by Mr. Pepys, for *ascertaining the quantity of carbonic acid discharged from any substance by the addition of an acid*. It consists of a bottle closed by a ground stopper. This stopper is perforated, and forms the lower part of a tube, which is twisted into the shape of a still-worm. In this worm, any water that escapes along with the gas is condensed, and falls down again into the bottle. The loss of weight is determined at the close of the effervescence.

FIG. 7. Mr. Leslie's *differential thermometer* described, vol. i. p. 89.

FIG. 8. (*a*) *An air thermometer*, for ascertaining the temperature of liquids. It consists of a bottle, partly filled with any coloured liquid, and partly with air, a glass tube of small bore, open at both ends, being either cemented or hermetically sealed into the bottle, so that its lower extremity may nearly touch the bottom of the bottle. The expansion of the included air, on the application of heat, drives the coloured liquid up the tube, to an extent which may be measured by the application of a scale. The fig. *b* is another variety of the same instrument, described vol. i. p. 89.

FIG. 9. The original *air thermometer of Sanctorio*; see vol. i. p. 88.

FIG. 10. A bent funnel for introducing liquids into retorts without soiling their necks.

FIG. 11. *An adopter*. The wider end admits the neck of a retort; and the narrower is passed into the mouth of a receiver.

FIG. 12. A section of an evaporating dish of Wedgwood's ware. Under this

figure is a representation, 12 *a*, of a small brass prong with a wooden or other handle, for holding an evaporating glass over a lamp.

Fig. 13. (*a*) *A tubulated retort* luted to (*b*) *a quilled receiver*, the pipe of which enters the neck of a bottle (*c*), supported by a block of wood.

Fig. 14. Different forms of jars for precipitations, with lips for conveniently decanting the fluid from the precipitate.

Fig. 15. A tube, blown in the middle into a ball, for dropping liquids. The ball is filled by the action of the mouth applied to the upper orifice, while the lower one is immersed in the liquid; or by immersing the ball and tube with its point downwards, in the liquid intended to be introduced. The finger is then applied to the upper orifice, and on cautiously removing it the liquid is expelled in drops.

Fig. 16. *A bottle for ascertaining the specific gravity of liquids.* When filled up to a mark on the neck, with distilled water of a given temperature, it should hold exactly an even number of grains; and a series of such bottles, holding respectively 200, 300, 500, 800, and 1000 grains, will be found extremely useful. The quantity which it is found to contain of any other liquid of the same temperature, shows at once the specific gravity of the latter. For example, if it hold 1000 grains of water, and 1849 of sulphuric acid, the specific gravity of the acid is to that of water as 1849 to 1000.

PLATE II.

Fig. 17. An apparatus for procuring gases, without the possibility of their escaping into the room during the process, a circumstance which is of importance, when the gas has an unpleasant smell or deleterious properties. Suppose that sulphureted hydrogen gas is to be obtained from sulphuret of antimony and diluted sulphuric acid. The sulphuret, in coarse powder, is put into the body of the gas bottle *c*, with a proper quantity of water. The acid holder *a* is filled with diluted acid, the cock *b* being shut, and is then fixed into the tubulure of the gas bottle, to which it is accurately adapted by grinding. The bent tube *d* being made to terminate under a receiver filled with, and inverted in, water, the perforated cock *b* is gradually opened, in consequence of which the acid descends into the gas bottle; and acts on the sulphuret of antimony. If it be found necessary to renew the acid, without disturbing the apparatus, this may be done as follows:—The cock *b* being shut, the stopper which closes the acid holder may be removed, and fresh acid be poured in through the aperture. This may be repeated as often as is found necessary. The acid holder may be advantageously adapted to a retort for certain distillations, such as that of muriatic acid. The shape, also, of the vessel *c* may be occasionally varied, as convenience may require. When, for example, it is shaped like the bottom part of a Nooth's machine (to be seen in almost every glass shop), it stands much more firmly on a table for use.

Fig. 18. A plain gas bottle with *sigmoid* tube, the end which is received into the bottle having a ground stopper accurately fitted to the neck. For ordinary purposes (such as obtaining hydrogen gas from diluted sulphuric acid and iron filings) this apparatus answers perfectly well, and is much less costly than that represented by fig. 17. It is frequently made with a tubulure and glass stopper, and is then called a tubulated gas bottle.

Fig. 19. *A gas funnel*, useful in transferring any gas from a wide-mouthed vessel into a jar of narrower diameter, or into a bottle. When employed for this purpose, it is held inverted, as shown by the figure, the pipe being admitted into the aperture of the bottle or jar, which is filled with and inverted in water, and the gas is then made to pass into it in bubbles.

Fig. 20. *Dr. Hope's Eudiometer.* The manner of using it has already been described, vol. i. p. 261.

Fig. 21. A modification of Dr. Hope's Eudiometer described, vol. i. p. 262.

Fig. 22. *A gas receiver*, into the neck of which is cemented a brass cap, with a female screw for receiving a stop-cock. The vessel *b* is a glass flask,

which may be made to communicate with the interior of the jar *a*, by opening the two air-cocks. Supposing that the weight of any gas is to be ascertained, the flask *b* is exhausted, by screwing it on the transfer of an air-pump; and, if great accuracy be required, it is proper to measure the degree of exhaustion by a fit gauge. Let the flask be weighed when exhausted; then screw it upon the top of the receiver containing the gas which is to be weighed; and open the communication, observing, by using a graduated jar, how much gas has been admitted. Suppose this to be 50 cubic inches. By weighing the flask again when full, we determine the weight of 50 cubic inches of the gas under examination. The experiment should be made when the temperature of the room is 60°, and when the barometer stands at 30 inches. (See vol. i. p. 30.)

Fig. 23. *A plain air-jar for receiving gases*, with a ground stopper.

Fig. 24. An *eudiometer* for trying the purity of a mixture of gases containing oxygen gas, by means of nitrous gas. The process has been described, vol. i. p. 277. The instrument should be accompanied with a phial, holding, when completely full, precisely a cubic inch.

Fig. 25. A wire stand, with a leaden foot, for the purpose of raising, above the surface of water within a jar, any substance which is to be exposed to the action of a gas.

Fig. 25. (*a*) A bottle and tube for directing a small stream, or a few drops of water, on any object. The method of using it is described, vol. i. p. 24.

Fig. 25. (*b*) A bottle with an elongated stopper, by means of which a single drop of any liquid can be taken up, and allowed to fall into any fluid under examination.

Fig. 26. An apparatus for showing that caloric exists in gases in a latent form; the application of it has been already described, vol. i. p. 127.

Fig. 27. An apparatus for drying precipitates by steam, described, vol. i. p. 24.

Fig. 28. A graduated tube for ascertaining the strength of acids and alkalies, and for various other useful purposes.

Fig. 29. (*a* and *b*.) Tubes for exploding mixtures of hydrogen and other inflammable gases with oxygen gas, commonly termed the *Eudiometer of Volta*; see vol. i. p. 262.

PLATE III.

Fig. 30. The common form of a *Woulfe's apparatus*. In this figure the retort *a* is represented plain, but it is better to employ a tubulated one. The use of this apparatus has already been described, vol. i. p. 21.

Fig. 31. A modification of the apparatus, which has been already described. In this figure, the mercurial trough is shown with a jar standing inverted in it, for the purpose of receiving any gas that may escape condensation by water.

Fig. 32. Mr. Pepys's improvement of Woulfe's apparatus, described, vol. i. p. 22.

PLATE IV.

Figs. 33 and 34. Cuthbertson's apparatus, for exhibiting the composition of water, with the substitution of gazometers for the receivers originally employed by him. The apparatus has been described, vol. i. p. 225. Fig. 33 is an enlarged view of the conical brass piece, which is cemented into the bottom of the receiver, and through which the gases are transmitted.

Fig. 35. A gazometer of the most simple and common construction; see vol. i. p. 28.

Fig. 36. A gas holder, described vol. i. p. 29.

Fig. 37. A galvanic trough; see vol. i. p. 159. The tube *b* shows the arrangement for decomposing water. The upper wire may be hermetically sealed into the tube, and the lower one passed through a cork, which should have a small slit cut in it, to allow the water to escape in drops as the gas is produced.

FIG. 38. The manner in which a candle may be burned in oxygen gas; see vol. i. p. 188.

FIG. 39. The combustion of iron wire in oxygen gas; see vol. i. p. 188.

FIG. 40. Apparatus for decomposing water over red-hot iron or charcoal; see vol. i. p. 228.

FIG. 41. An apparatus for showing the diminution effected in the volume of hydrogen and oxygen gases by their slow combustion; see vol. i. p. 219.

FIG. 42. A very simple and cheap contrivance for freezing quicksilver by muriate of lime and snow. The outer vessel of wood may be twelve and a half inches square, and seven inches deep. It should have a wooden cover, rabetted in, and furnished with a handle. Within this is placed a tinned-iron vessel, *b b*, standing on feet which are one and a half inch high, and having a projection at the top, half an inch broad, and an inch deep, on which rests a shallow tin pan, *c c*. Within the second vessel is a third, *d*, made of untinned sheet-iron, without any solder at the corners, and supported by feet two inches high. This vessel is four inches square, and is intended to contain the mercury. When the apparatus is used, a mixture of muriate of lime and snow is put into the outer vessel *a a*, so as completely to surround the middle vessel *b b*. Into the latter the vessel *d*, containing the quicksilver to be frozen, previously cooled down by a freezing mixture, is put; and this is immediately surrounded by a mixture of snow and muriate of lime, previously cooled to 0° Fahrenheit, by an artificial mixture of snow and common salt. The pan *c c* is also filled with these materials, and the wooden cover is then put into its place. The vessels are now left till the quicksilver is frozen. A more elegant, but more expensive apparatus, by Mr. Pepys, intended for the same purpose, is figured in an early volume of the Philosophical Magazine.

FIG. 43. A wire stand, consisting of an interior circle, and three straight pieces of wire proceeding from it in the same plane. Its use is noticed, vol. i. p. 177.

FIG. 44. Sir H. Davy's apparatus for the analysis of soils.

PLATE V.

FIG. 45. Pictet's arrangement of an apparatus for showing the radiation of caloric, unaccompanied by light; see vol. i. p. 95.

FIG. 46. An oval copper boiler, (referred to vol. i. p. 119), for exhibiting the most important facts respecting latent caloric. The size of its different parts (except the width, which is 4 inches) may be learned from the scale affixed to the plate, which is abundantly sufficient to enable any intelligent workman to construct the apparatus. The collar joint and stuffing box, however, it is indispensably necessary to describe, especially as the former article of apparatus is generally constructed on a bad plan.

FIG. 47 is a section, upon a larger scale, of the collar joint at *b* (fig. 46) made for the convenience of screwing together long or crooked metal tubes, without turning them round; *a* is a section of the end of one of the tubes, and *b* that of the other which is to be attached to it; *c* is a collar which turns loose upon the shoulder of *a*, and screws upon *b*. By screwing this collar upon *b*, the end *e e* of the tube *a* is brought to press upon the part *d d* of the tube *b*, without turning round either of those tubes. If upon *d* be laid a ring of linen cloth soaked in boiled linseed oil, the joint, when screwed up (if tolerably well made), will be impervious to steam as well as to water or air. The projection at *d* is for preserving the ring of cloth from being displaced, and for guiding the ends of both tubes, so as to meet properly.

FIG. 48 is a section of a socket for fixing the stem of a thermometer into a boiler or a digester, where there is much heat and pressure; *b* is a socket fixed on the outside of the boiler or digester, having a hole through it large enough to admit the bulb of the thermometer; *a* is a plug which screws into *b*, having a hole through its centre large enough to admit only the stem of the thermometer. *e e* is a loose round plate, concave on the upper side, having a hole through its centre just sufficient also to admit the stem of the thermometer. When the instrument is to be inserted, the plug *a*, and the plate *c*, must both be taken out of the socket. The bulb is then passed through it. The plate *c* is next slipped over the stem, and dropped into its place. Some flax, soaked in linseed oil, must next be wrapped round the stem, so as nearly to fill the socket. The plug *a* must then be screwed in, till the flax be compressed so as to make the whole sufficiently tight. The opposite surface of the plate *c*, and the plug *a*, are made concave, for the purpose of compressing the flax round the stem of the thermometer. The gage represented above the cock *c* at the top of the boiler is adapted to show the density of the steam, by its effect on a portion of air confined by mercury; for the volume of the air will of course be inversely as the compressing force. The bent part of this gauge and small ball are of iron, and the straight part only, where the mercury is to be seen through, should be of glass.

PLATE VI.

FIGS. 49, 50, 51. Sections of crucibles.

FIG. 52. A muffle; see vol. i. p. 19.

FIG. 53. Stands for raising the crucible above the bars of the grate; *a* one adapted to Mr. Aikin's blast furnace; *b* one of the common form.

FIG. 54. A skittle-shaped crucible.

FIG. 55. Mr. Aikin's portable blast furnace. It is composed of three parts, all made out of the common thin black-lead melting pots, sold in London for the use of goldsmiths. The lower piece *c* is the bottom of one of these pots, cut off so low as only to leave a cavity of about an inch, and ground smooth above and below. The outside diameter over the top is five and a half inches. The middle piece, or fire-place *a*, is a larger portion of a similar pot, with a cavity about six inches deep, and measuring seven and a half inches over the top, outside diameter, and perforated with six blast holes at the bottom. These two pots are all that are essentially necessary to the furnace for most operations; but when it is wished to heap up fuel above the top of a crucible contained within, and especially to protect the eyes from the intolerable glare of the fire when in full heat, an upper pot *b* is added, of the same dimensions as the middle one, and with a large opening in the side, cut to allow the exit of the smoke and flame. It has also an iron stem, with a wooden handle (an old chisel answers the purpose very well) for removing it occasionally,

The bellows, which are double (*d*), are firmly fixed, by a little contrivance, which will take off and on, to a heavy stool, as represented in the plate; and their handle should be lengthened so as to make them work easier to the hand. To increase their force on particular occasions, a plate of lead may be firmly tied on the wood of the upper flap. The nozzle is received into a hole in the pot *c*, which conducts the blast into its cavity. From hence the air passes into the fire-place *a*, through six holes of the size of a large gimblet, drilled at equal distances through the bottom of the pot; and all converging in an inward direction, so that, if prolonged, they would meet above the centre of the upper part of the fire. Fig. 56 shows the distribution of these holes in the bottom. The large central hole is intended to receive the stand *a*, fig. 53, which serves for supporting the crucible.

No luting is necessary in using this furnace, so that it may be set up and taken down immediately. Coke or common cinders, taken from the fire when the coal just ceases to blaze, sifted from the dust, and broken into very small pieces, forms the best fuel for higher heats. The fire may be kindled at first by a few lighted cinders, and a small quantity of wood-charcoal.

The heat which this little furnace will afford is so intense, that its power was, at first, discovered accidentally by the fusion of a thick piece of cast iron. The utmost heat procured by it was 167° of Wedgwood's pyrometer piece, which was withdrawn from a Hessian crucible, when actually sinking down in a state of porcellanous fusion. A steady heat of 155° or 160° may be depended on if the fire be properly managed and the bellows worked with vigour. (See Philosophical Magazine, vol. xvii. p. 166.)

By a letter from Mr. Aikin, I have learned, also, a convenient way of exhibiting in a lecture, and performing at other times, the process of cupellation, by means of this furnace. It consists in causing a portion of the blast to be diverted from the fuel, and to pass through a crucible in which the cupel is placed. This arrangement supplies air, and the whole may be seen by a sloping tube, run through the cover of the crucible. Fig. 57 shows the furnace when used for this purpose; *a a* the furnace; *b* the perforated stopper for the central blast; *c c* a portion of earthen tube, through which the air passes, and is heated during this transit; *e* a piece of soft brick, perforated to admit the earthen tube *f*, which may be kept open for inspecting the process. No luting is required, except to join *f* to *e*.

It may be proper to add, that Mr. Aikin has lately (1823) made considerable improvements in this useful little furnace, which may be had, thus altered, of Mr. Knight, in Foster-lane. The principal one is the enlargement of the air chamber *c*. In using the furnace, Mr. Aikin has found that its power is greater when the pipe of the bellows is not actually introduced into the opening leading to the air chamber, but kept at the distance of from one to two inches. He uses, also, a straight tube of communication between the bellows and the air chamber, in preference to one bent as shown in the figure.

Fig. 58. Knight's portable furnace, (described also in p. 19,) composed of strong iron plate lined with fire lute, the inside diameter six inches: *a* shows the grate; *b* the ash-pit door; *d* the door of the fire-place when used as a sand heat; *e e* two holes opposite to each other for transmitting a tube; *g* an opening for a retort neck, when used for distilling with the naked fire.

Fig. 59. A different view of the same furnace; *a* the grate; *c* the register to the ash-pit; *f* a small door, with a contrivance for supporting a muffle. The other letters correspond with the explanation of the preceding figure.

For this furnace the proper fuel, when it is used as a wind furnace, is wood-charcoal, either alone or with the admixture of a small proportion of coke. For distillation with a sand-heat, charcoal, with a little pit coal, may be employed.

PLATE VII.

Fig. 60 represents a fixed furnace, which I find very useful, because it may either be employed as a wind furnace or for distillation with a sand heat. Its total height outside is thirty-three inches, and the outside square is eighteen inches, or two bricks laid lengthwise. The thickness of the sides of the furnace is the breadth of a brick, or four and a half inches; but whenever there is room, it is better to make them nine inches in thickness. From the top of the furnace to the grate, which is moveable, and supported by two bearers, the height is thirteen inches; and at *c* is a double Rumford door; or in preference, a hole, closed by a moveable earthen stopper, for introducing fuel. The ash-pit should have a register door. The chimney is four inches wide by three high, and may either be furnished with a damper or not. On the top of the furnace a cast-iron ring is fixed, ten inches inside diameter, three inches broad, and half an inch thick. It is secured in its place by three iron pins, passing through three equidistant holes in the ring, and bent at the distance of nine inches at a right angle. These serve the purpose of binding the ring firmly into the brick-work. The sand pots are of different sizes; and a variety of them may be made to fit the same ring, by varying the breadth of their rims, as shown fig. 71. The bricks should be cemented together, at least for the inner half of their breadth, by loam, or by a mixture of Stourbridge clay, with two or three parts sand, and a proper quantity of water.

When this is used as a wind furnace, the opening in the side is to be closed by its stopper; or, if a Rumford door be employed, it must be defended from the fuel by a fire tile. The fuel (coke) is introduced at the top, which is occasionally covered by a fire tile. When distillation with a sand heat is performed, the sand pots rest on the iron ring, and the fuel, which may be common pit coal, is added through the opening in the side. It may be proper to state, that, in order to receive a sand pot of as large a size as possible, the upper course of bricks should be bevelled within the furnace; and the width at the top may exceed a little that at the grate.

The best Stourbridge or Newcastle-on-Tyne fire-bricks are necessary in constructing this and the following furnaces.

Fig. 61 is a longitudinal section of a wind furnace, invented by Mr. Knight, with an additional chamber for applying the waste heat to useful purposes: *a* the internal cavity, which is square, for containing the fuel and the crucible; *b* the flue passing into a hot chamber *c*, an appendage particularly useful for drying luted crucibles, or bringing them to a proper temperature for the furnace; for roasting ores and various other purposes: *d* the flue connecting it with the vertical chimney *e*; which, to produce a strong heat, should never be less than thirty or forty feet high: *f f* covers, consisting of twelve-inch Welsh tiles, with handles; *g* the stoke hole, through which no more of the fire is seen than what appears between the grate and the bearing bar *h*. This space is left for the double purpose of raking the fire, and occasionally taking out the bars: *k* the ash-pit, which is sunk below the level of the ground, and is covered, where it projects at *l*, by an iron grating.

The best situation for this furnace is an angle of the laboratory, the chimney being in the corner, as represented in the sketch. By this arrangement, the operator is spared the disagreeable necessity of scorching his legs, by standing opposite the stoke hole, while the backs of his legs are exposed to a current of cold air rushing to the furnace.

Figs. 62 and 63 are different views of a furnace invented by Mr. Knight, and convertible to various purposes.

The inside of this furnace is nine inches square, and sixteen inches deep from the top to the grate. The face of the opening at *g* rises at an angle, which makes the back part five inches higher than the front. This contrivance enables us completely to cover a large retort with fuel, without obstructing the passage of the air, and also relieves partly the weight of the cover, when it requires to be moved. The walls of the furnace are at least a brick and a half thick, and as much more as local convenience will allow. By sinking the ash-pit below the level of the ground, at *i*, the height of the furnace needs not exceed eighteen inches, which renders the management of the fuel much more easy, and subjects the face and hands less to the action of the heat. The ash-pit *a*, must be at least eighteen inches deep, below the surface of the ground, and more if convenient. It must have an opening, projecting from it three or four feet, to be covered with boards, and with an iron grating next the furnace. This preserves the legs of the operator from the action of the fire.

The grate *b* is formed of separate bars, each of a triangular shape, three-fourths of an inch apart, and resting on two bearers. In the front of the furnace, an iron bar is to be placed to support the brick-work, and to leave an opening, through which the bars may occasionally be drawn out, and the fire raked and cleared of the slag. The chimney *e* is two and a half inches from the top, and four and a half wide by two and a half high.

To fit this furnace for occasional distillation with the naked fire, an opening *d*, fig. 62, is left on one side, which is filled up, when not wanted, by five pieces of soft fire-brick, cut to a proper shape, and secured by a clay lute. It is proper, also, to be provided with other pieces, having arched openings for transmitting the neck of a retort. One of these pieces may have a round hole for occasionally transmitting a tube, and a corresponding hole, *h*, fig. 63, must then be made in the opposite side of the furnace, to be closed, when not wanted, with a stopper.

Figs. 64 and 65 represent a sand heat, for containing flat evaporating vessels: the depth from back to front two feet; the width, agreeably to the scale, six feet. At the front is a rim four inches deep, consisting of a piece of iron plate, which is fastened at each end into the wall. The floor or bottom *e e*, is formed of cast-iron plates, which rest upon each other in corresponding rabbets. The advantage of several small plates, over one large one, is the cheapness and facility with which they are replaced, if cracked by the heat, an accident of not unfrequent occurrence. The joints are secured by a fire lute, which effectually prevents the sand from falling through. The fire-place is shown by *b*; at the bottom it has a grate ten inches long, by eight wide. The flame and smoke circulate first through the flue *c*, and then through the returning flue *d*, which conveys the smoke to the chimney *g*. In constructing the flue beneath the grate, a row of bricks, set edgeways, answers the purpose, and serves also to support the inner edge of the plates.

It is advisable to cover the sand heat with a sloping roof, which may be formed of lath and plaster, and supported by side walls. The lowest part of the roof may be foremost, and about three feet above the edge of the iron plates. It is, also, necessary to have an air flue, nearly at the top of the back wall, under the dome or roof, to be closed occasionally by a door. This must open into the chimney, in which case it serves the purpose of carrying off noxious vapours.

PLATE VIII.

Figs. 66, 67, 68, are the sections and plans of a reverberatory furnace for experimental purposes. In this furnace, the fuel is contained in an interior fire-place; and the substance, to be submitted to the action of heat, is placed on the floor of another chamber, situated between the front one and the chimney. The flame of the fuel passes into the second compartment; by the form of which it is concentrated upon the substance exposed to heat, which is not confined in a separate vessel or crucible, but placed on the floor of the furnace. When reduced to a state of fusion, the melted mass is allowed to flow out through a tap-hole at *h*. The dimensions of this furnace it is scarcely possible to state, as they vary so considerably in different parts of it; but they may be ascertained by referring to the figures, and by the application of the scale. In all three figures *a* represents the ash-pit; *b* the grate composed of moveable bars; *c* the door at which the fuel is introduced; *d* a door in the side of the chamber, for the purpose of inspecting the process; *e* the floor of the furnace which descends, and is gradually contracted towards the back part; *f* another door for introducing and stirring the materials; *g* the back part of the furnace, immediately under the chimney; *h* the tap-hole; *i* the chimney.

Figs. 69 and 70, exhibit a cupelling or *enamelling furnace*. The form of this should be an oblong square; its dimensions being regulated by that of the muffle, which should go home, to the back, its front edge lodging on the mouth of the furnace. On each side of the muffle, two inches and a half must be left, to let the fuel pass readily underneath, where there should also be a similar space. A stoke hole must be left on the other side, but the situation of the view will not admit its being shown. Before the muffle, is a projecting ledge or shelf, shown at *e*, which is intended to support any thing that is to be put into the muffle. Two twelve-inch tiles, worked in along with the bricks, will answer this purpose. In both figures, *a* shows the ash-pit; *c* the grate; *d* the muffle; *e* the opening for introducing the muffle; *f* the chimney, and *g* the cover.

Fig. 71. Sand pots with rims of different sizes.

Figs. 72, 73. Dr. Black's portable furnace, made of sheet iron lined with fire clay. Its dimensions, as they vary in almost every part, will best be learned from the scale; *a* the fire-place; *b* the chimney; *c* the ash-pit; *d* the door of the ash-pit; *e* a register for regulating the quantity of air admitted to pass through the fuel.

Fig. 74. Mr. Chevenix's wind furnace. This is rudely sketched in Nicholson's Journal, from which the more accurate figure in plate viii. is taken. This furnace Mr. Chevenix describes as follows: "I have constructed a wind furnace, which, in some respects, is preferable to the usual form. The sides, instead of being perpendicular, are inverted; so that the hollow space is pyramidal. At the bottom the space is twelve inches square, and at the top only eight. The perpendicular height is seventeen inches, from the top to the grate. This form unites the following advantages. 1. A large surface is exposed to the air, which, having an easy entrance, rushes through the fuel with great rapidity. 2. The inclined

sides act as reverberators. 3. The fuel falls of itself, and is always close to the grate."

In the figure, *a* represents the grate : *c c* are two bricks, which can be let in at pleasure, to diminish the capacity : *b* is another grate which can be placed on the bricks *c c*, for occasional purposes : *d d* are bricks, which can be placed on the grate *b*, to diminish the capacity of this part of the furnace ; *e* the cover. Both set of bricks should be ground to the slope of the furnace.

In the construction of every furnace, which is intended to produce a strong heat, lime or mortar should be avoided, and the bricks should be set in loam, or Stourbridge clay, worked up with water and sand, inserting occasionally pieces of sheet iron, bent twice in opposite directions at right angles. The furnace should be allowed to remain some weeks, after setting up, before it is used ; and before raising a strong heat, a gentle fire should be sometimes kindled in it, the strength of which may be gradually increased. When a strong blast is expected, it is necessary to bind the brickwork together, externally, by strong iron bars and plates, kept in their places by screws. The chimney should be nine inches wide, and raised to as great a height as circumstances will admit.

The coke of pit coal is the only fuel fitted for exciting an intense heat, and should be used in all cases, except in the reverbatory, and in distillations with the sand bath, when pit coal may be employed. The charcoal of wood is adapted principally to portable furnaces.

PLATE IX.

FIG. 75. The galvanic battery called *courronne de tasses*, described vol. i. p. 160.

FIG. 76. Apparatus for obtaining the elements of water in separate tubes ; see vol. i. p. 166.

FIG. 77. The pile of Volta ; see vol. i. p. 159. The tube annexed to the pile is for the purpose of showing the decomposition of water ; see vol. i. p. 166.

FIG. 78. Section of a galvanic trough, to explain the theory of the excitation of galvanic electricity ; see vol. i. p. 175.

FIG. 79. Apparatus for obtaining oxygen and hydrogen gases, from separate quantities of water not in contact with each other ; see vol. i. p. 167.

FIG. 80. Two agate cups connected by moistened amianthus ; see vol. i. p. 167.

FIG. 81. Two gold cones similarly connected, p. 168.

FIG. 82. Agate cups similarly connected with an intermediate vessel *i* ; see vol. i. p. 169.

FIG. 83. Apparatus for procuring potassium from potassa and iron filings. A better apparatus for this purpose is represented by the wood cut, vol. i. p. 442.

FIG. 84. Apparatus for firing gases by electricity, or submitting them to electrical discharges, vol. i. p. 30.

FIG. 85. Pepys's improved gas-holder : *a* a small iron retort placed in the fire with a jointed conducting tube *b*, which is admitted into the vessel at *c*. This is shown on a larger scale in a different part of the plate. The letter *d* is placed on the body of the reservoir, and near the central pipe, which descends from the cistern *e* to nearly the bottom of the vessel. At *f* a glass tube is fixed, which shows the height of the water within the vessel. When a jar is intended to be filled with gas from the reservoir, it is placed, filled with water and inverted, in the cistern *e*. The cocks 1 and 2 being opened, the water descends through the pipe attached to the latter, and the gas rises through the cock 1. By raising the cistern *e* to a greater elevation, any degree of pressure may be obtained ; and a blow-pipe may be screwed on the cock at the left side of the vessel.

PLATE X.

FIGS. 1, 2, 3. Views of Mr. Newman's *Mercurio-pneumatic trough*, combined with a mercurial gazometer. The same letters refer to all three figures.

FIG. 1, is a front view ; fig. 2, a section ; and fig. 3, a view looking down from above into the cavity of the trough. A, the glass bell of the gazometer, shown about half full of gas; B, the exterior vessel of the gazometer. In fig. 1. the central solid part, which fills the cavity of the bell when depressed as far as it will go, is shown by dotted lines, as also is a small iron tube, on which the letter B stands. This tube conveys the gases from the small bell-shaped vessel E, in which they are first received, into the receiver A of the gazometer. In fig. 2, this tube is marked *b b*, and may be seen rising a little above the mercury, which is thus prevented from falling into it. In fig. 3, the termination of this pipe is marked by a circle, close to the letter C.

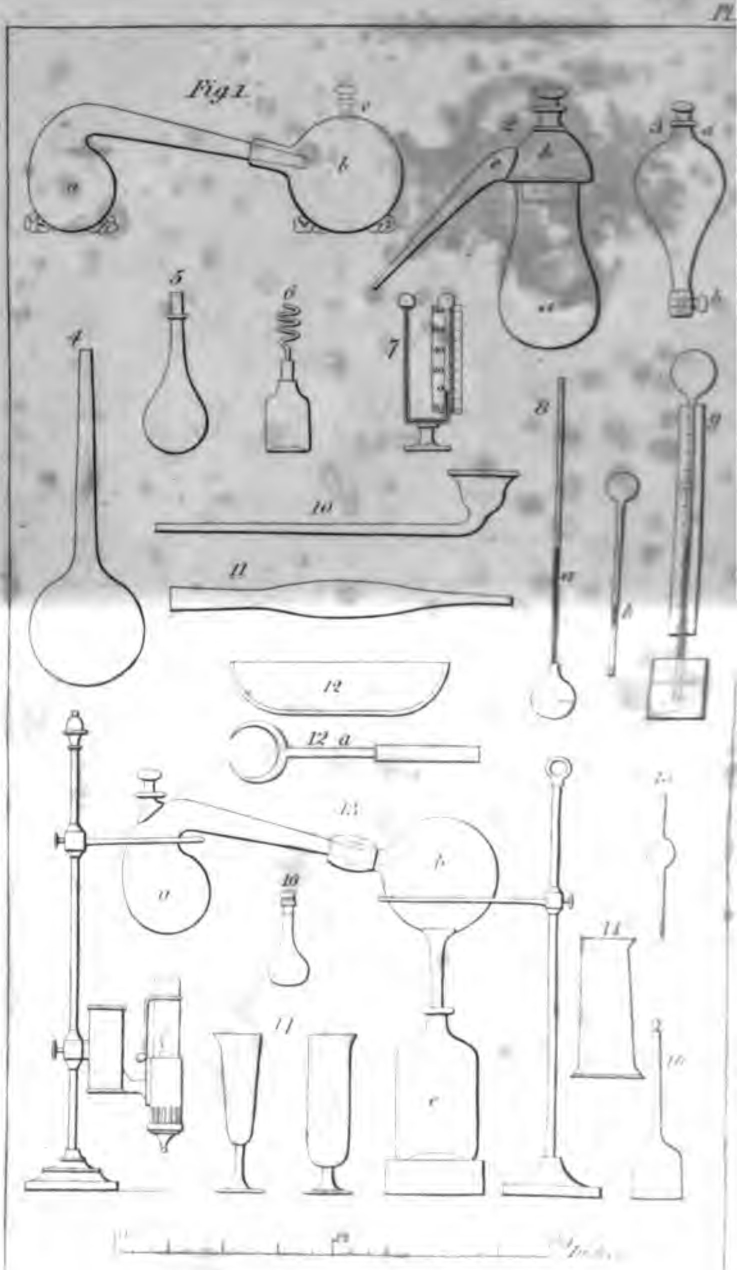
D, fig. 1, one of the sides of the cistern for containing mercury; at G the cistern has a semi-cylindrical cavity seen more distinctly in fig. 2. F is a small tube opening into the gazometer, and also under one of the small holes *i i i*, fig. 3. By means of this tube, a small portion of gas may, at any time, be transferred from the gazometer into a narrow test tube or other vessel. H is a deep circular cavity, or well, into which a long tube or jar may be occasionally immersed, when it is necessary to have the mercury at the same level within and without. I is a receiver into which gas is supposed to be passing from a retort heated by the spirit lamp N. This lamp, by means of a pillar and socket, may be raised or lowered at pleasure, and is secured at any desired height by a spring. K, a Volta's Eudiometer secured by an upright pillar L, in which is a spring to diminish the recoil on firing any gases. This is moveable, and is fixed when wanted to the side of the trough by the screws M. O O, a sheet iron tray, intended to collect any mercury that may be spilled out of the trough.

Figs. 4, 5, 6, 7. The *compound blow-pipe for compressed oxygen and hydrogen gases*, with the addition of a safety tube for preventing explosions. A, the barrel of the condensing syringe. B, the handle of the piston. C, a cock for closing occasionally the communication with a bladder filled with the mixed gases. D, a cock between the syringe, and the square copper box into which the gases are condensed. This box is marked E. F, a perforated metal cap fitted by a screw to the top of the box, and containing a pile of circular discs of wire gauze, seen in fig. 5, such as is used for the safety lamps. G, a cock to prevent occasionally the escape of the condensed gases. H, a ball and socket joint, by means of which the jet I, of which there should be two or three of different sizes, can be turned in any direction.

The addition to the apparatus for preventing explosions is represented in fig. 5, within the copper box. The letter *d* is placed on a piece of brass tube closed at the bottom, and fixed air tight into the box. Into the bottom of this is fixed a small pipe *a a*, covered at the upper extremity *a* by a piece of wire gauze, and opening into the brass tube by two or four holes. A circular flat valve, lined with silk or leather, which may be seen in the sketch, covers these holes, and prevents the passage of any thing backwards from the brass tube into the box E.

When the instrument is to be used, the common air should be exhausted from the box E, by means of the syringe, the box then filled with the gases; after which water or oil should be poured into the brass tubes (the cap F being supposed removed) to about *e*. The gases may then be condensed into the box, and by their own elastic force will pass through the tube, the fluid, and the various screens of wire gauze, and will issue out at the jet. When the inflammation, by the use of a large jet, passes backwards, it is generally arrested by the discs of wire gauze; but if it pass these, it kindles only the gases in the brass tube, and does no harm; and the valve prevents the fluid from being propelled into the box.

END OF VOL. I.

Pl.
Fig. 1.
a
b
c
2
c
b
a
3
a
b
4
5
6
7
8
a
b
9
10
11
12
12 a
13
a
b
c
16
14

Pl. II.

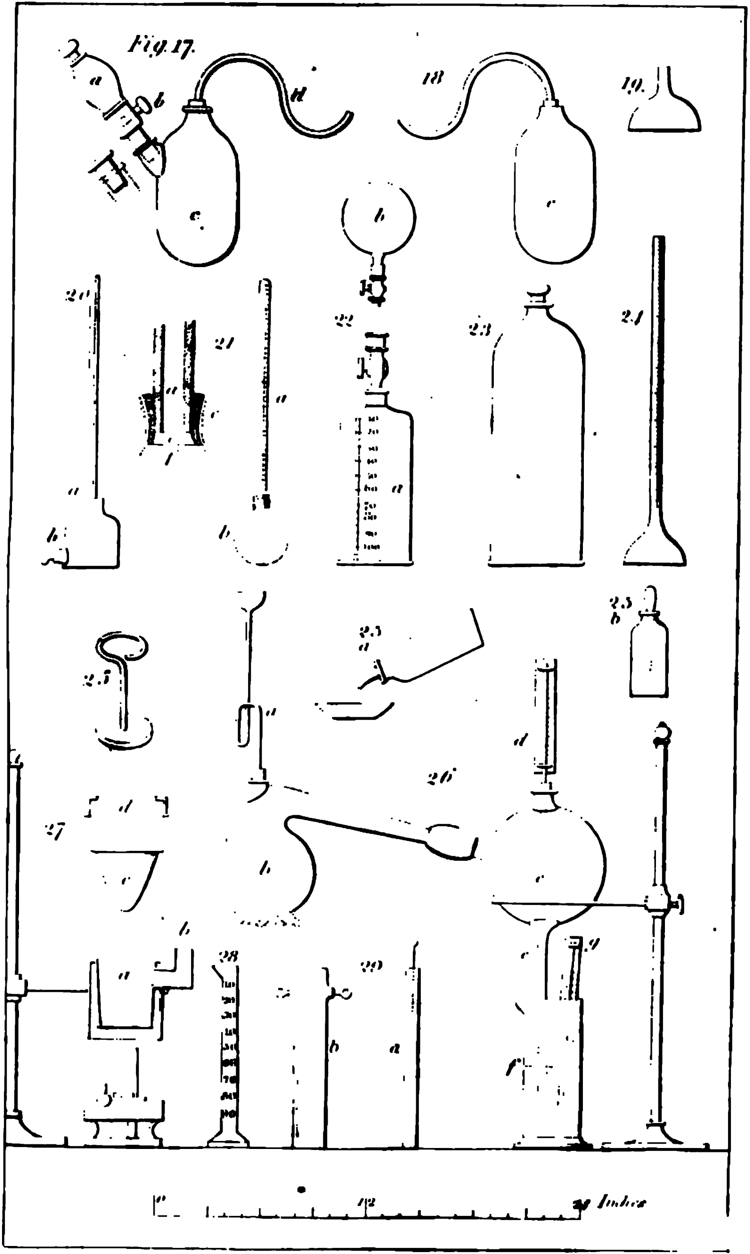
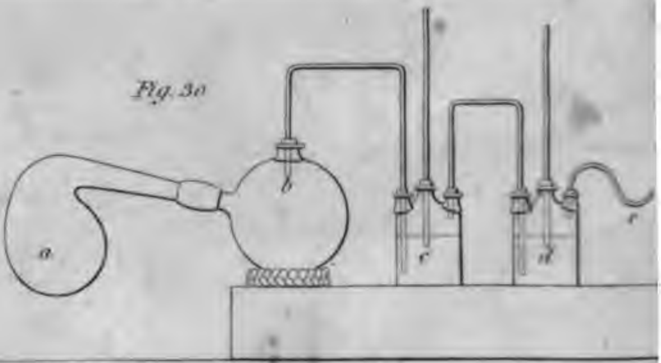


Fig. 17.
a
b
d
c
18
c
19.
b
20
a
b
21
a
c
f
a
b
22
a
23
24
25
25 a
25 b
a
26
d
c
e
27
d
c
b
a
28
29
30
b
a
f
g
0
12
24 Inches

Fig. 30



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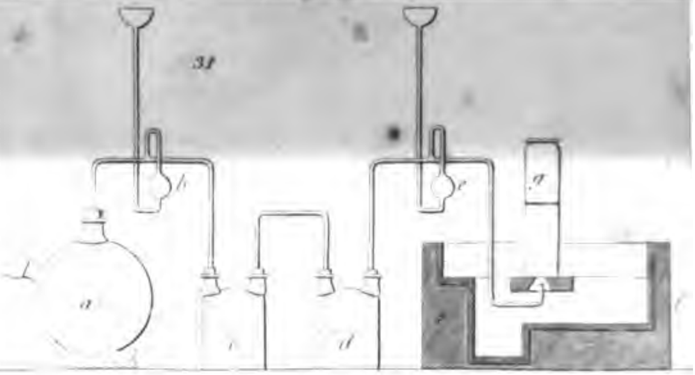

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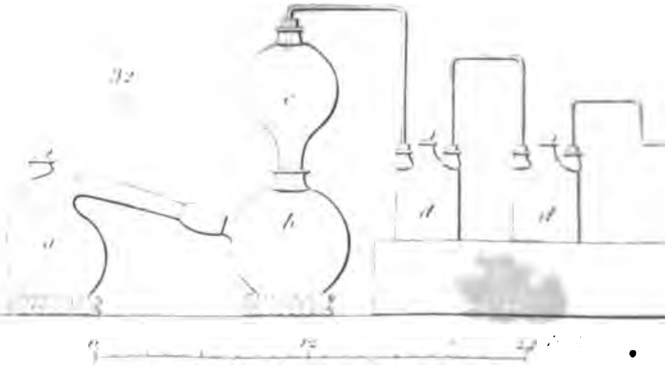


Pl IV

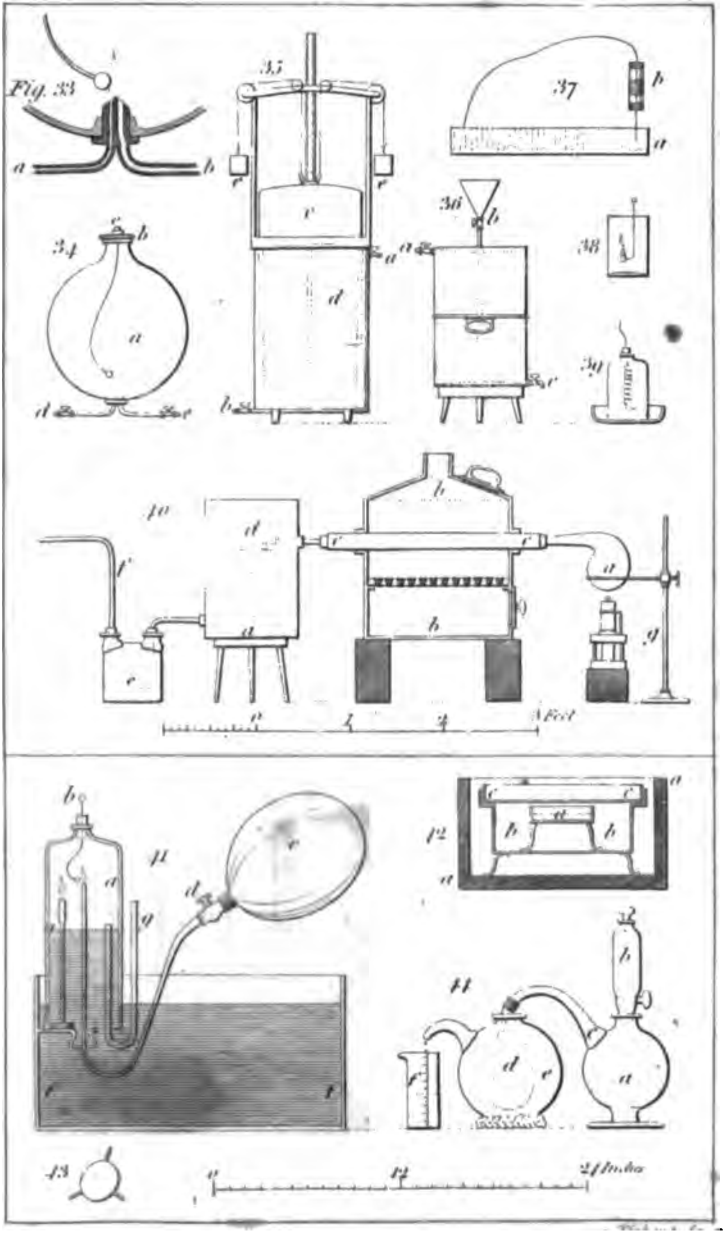
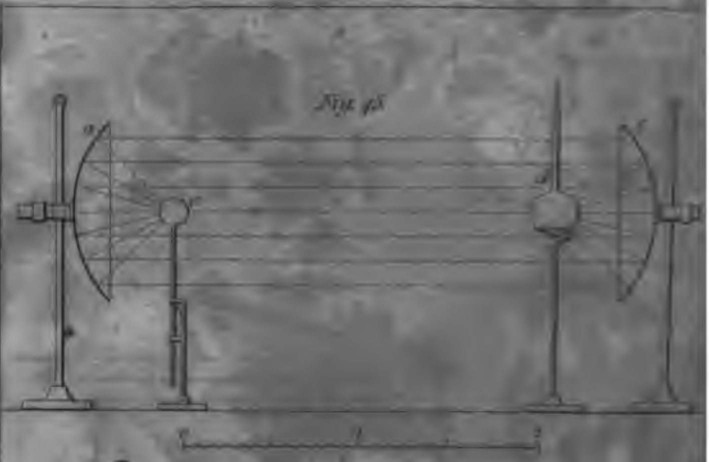
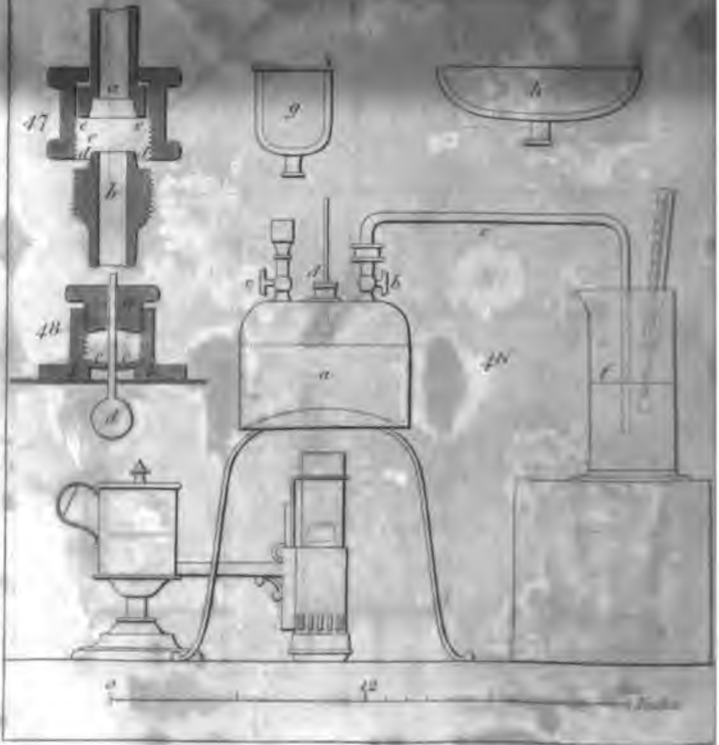


Fig. 33
a
b
34
c
b
a
d
e
35
c
c
e
d
a
b
36
a
b
c
37
b
a
38
39
40
f
e
d
a
c
c
b
b
g
0
1
2
3 Feet
41
b
a
g
c
d
f
f
42
a
c
c
d
b
b
a
43
44
d
e
f
a
b
0
12
24 Inches

Fig. 45





Pl. 17.

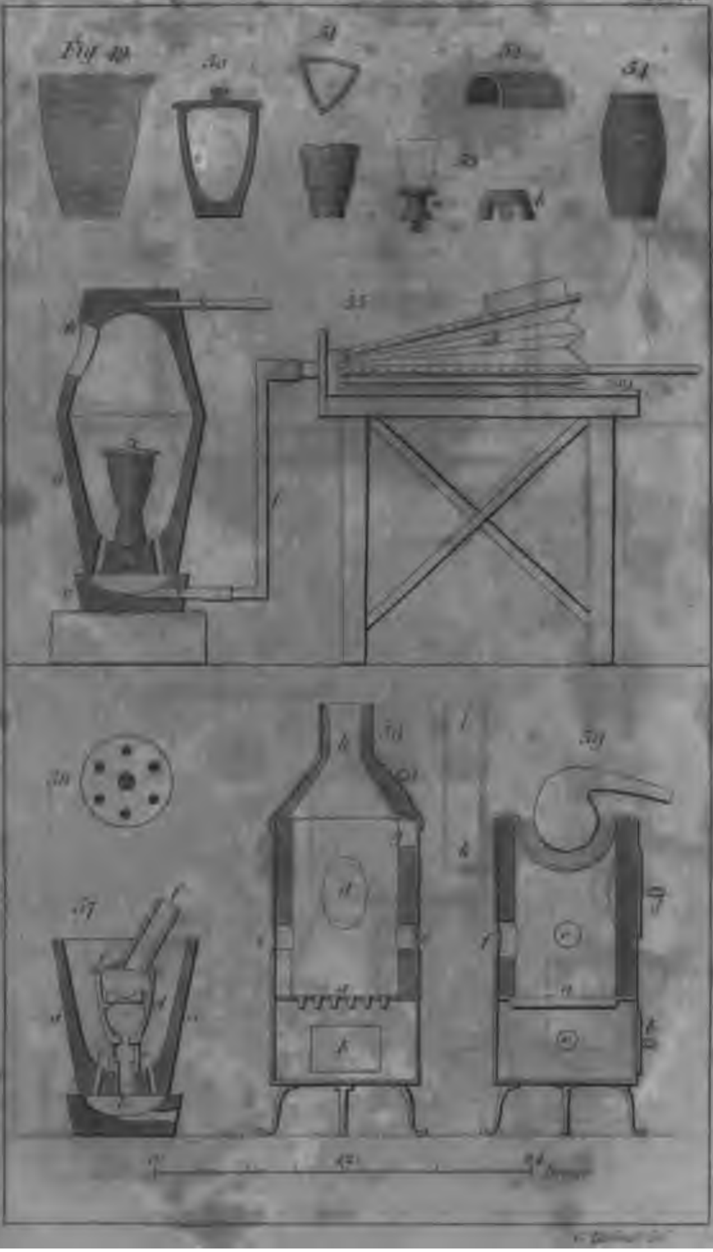
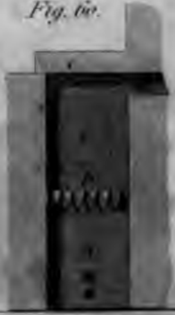


Fig. 60.



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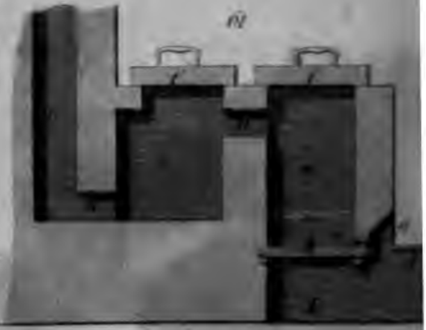

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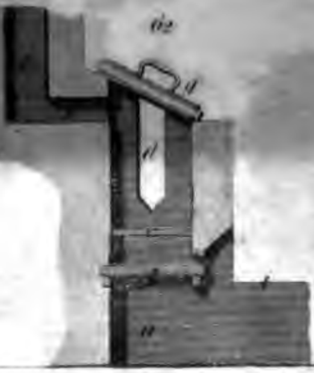

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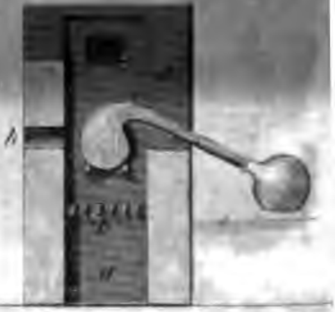

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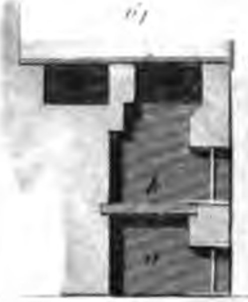

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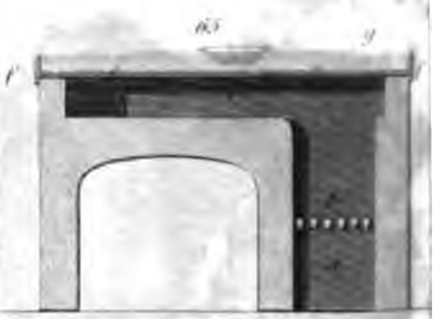

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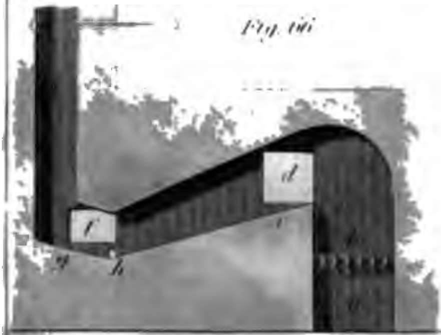

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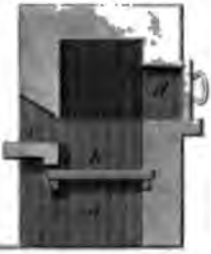

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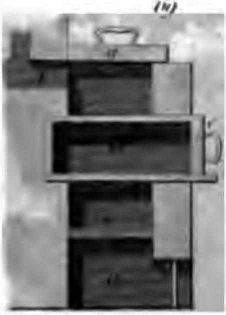

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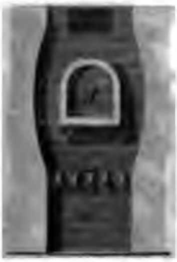

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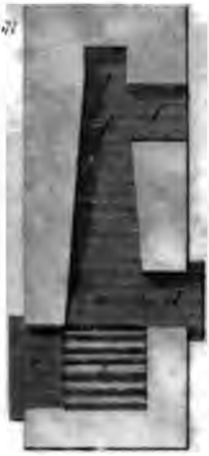

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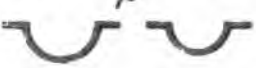

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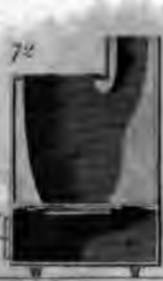

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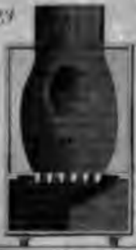

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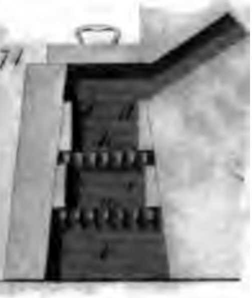

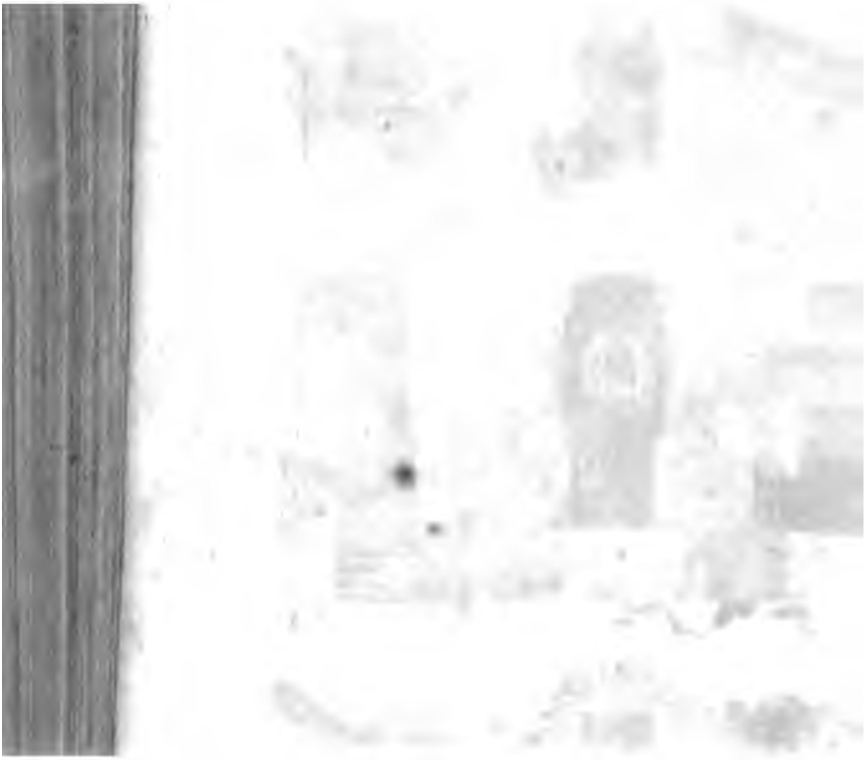

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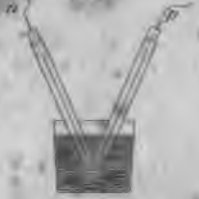

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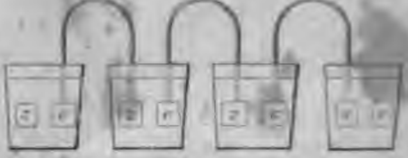

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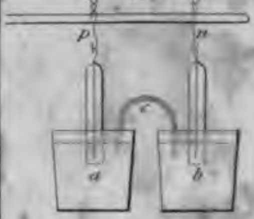

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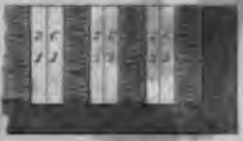

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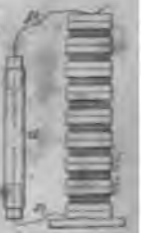

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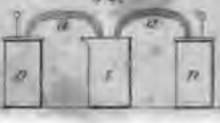

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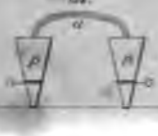

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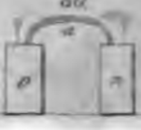

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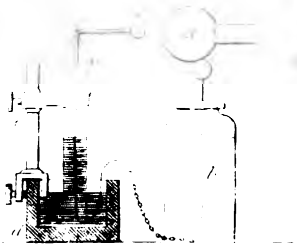

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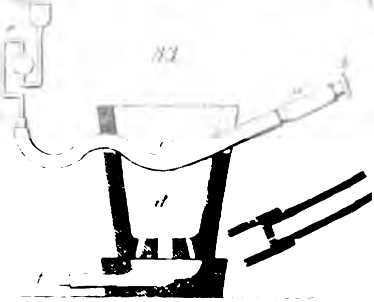

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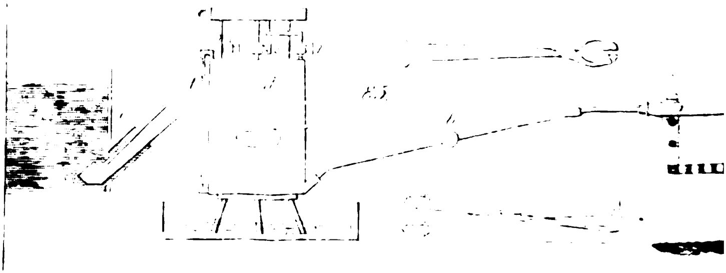
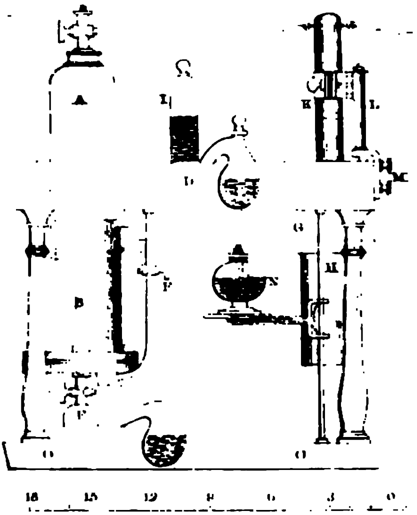


Fig. 1



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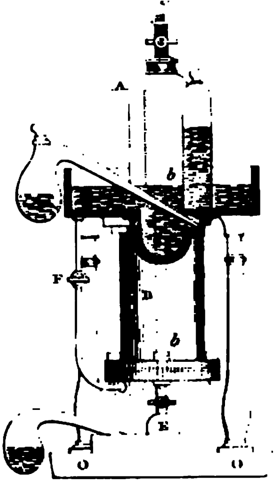
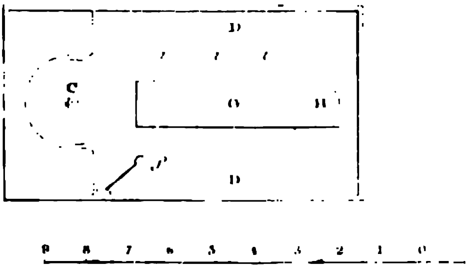


Fig. 3



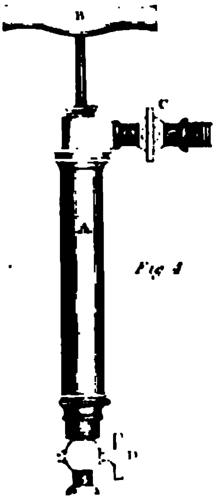
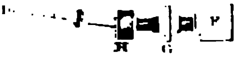


Fig. 4

Fig. 6



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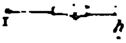

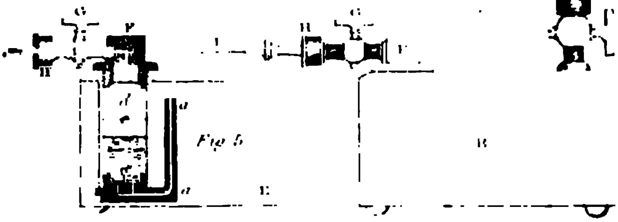
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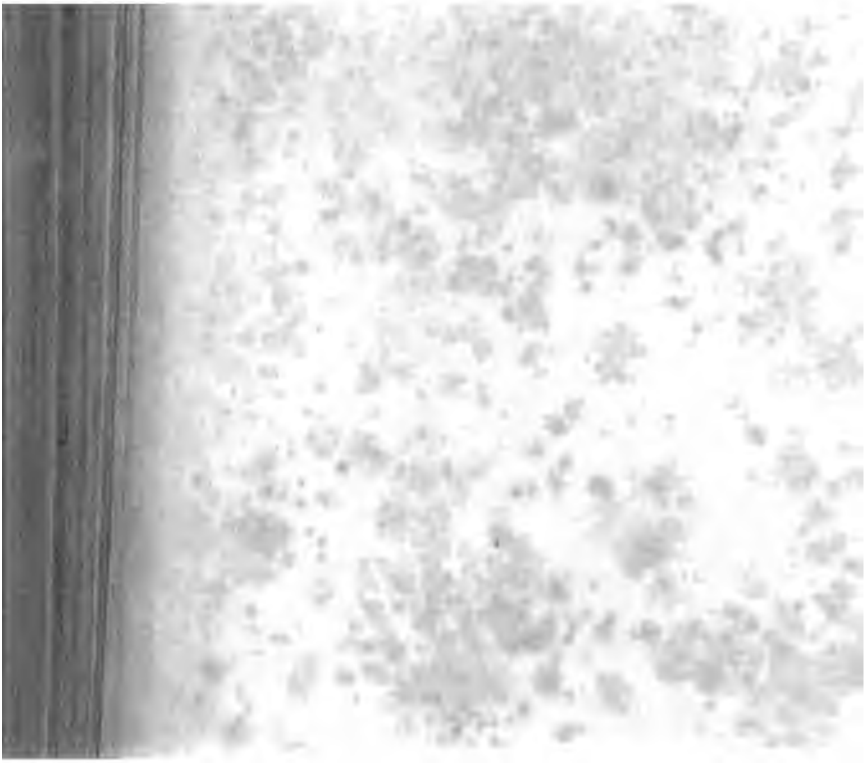

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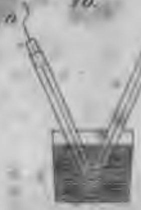

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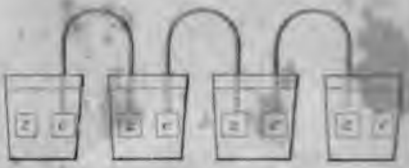

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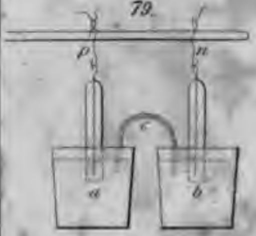

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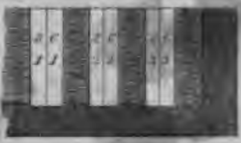

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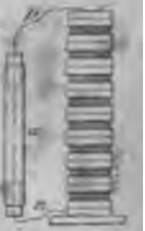

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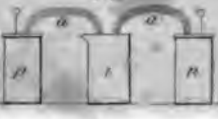

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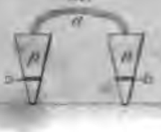

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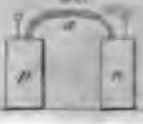

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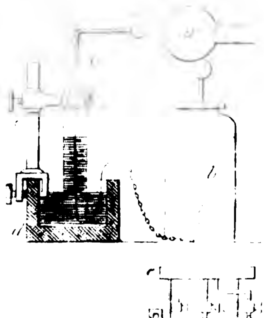

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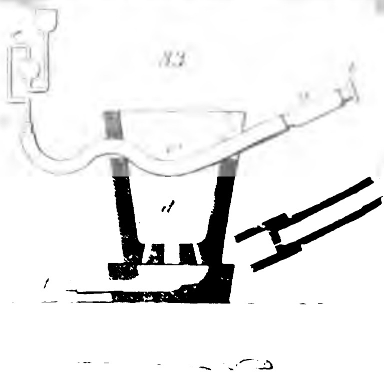

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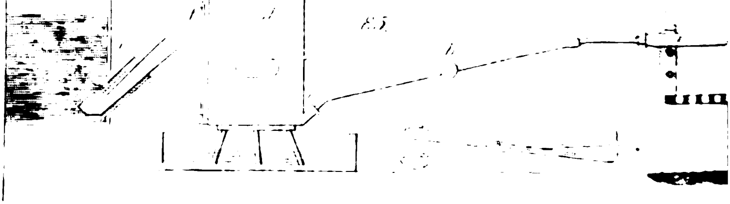
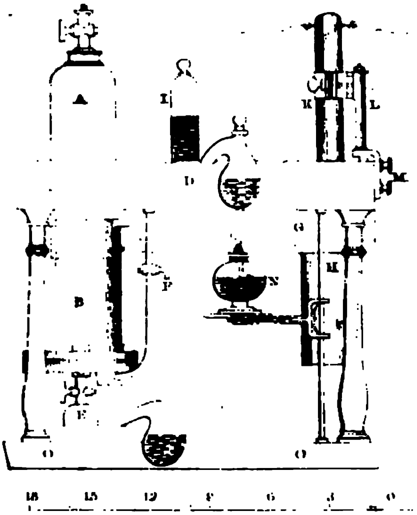


Fig 1



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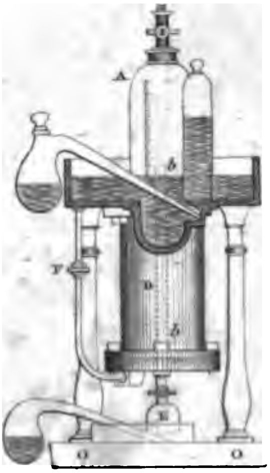

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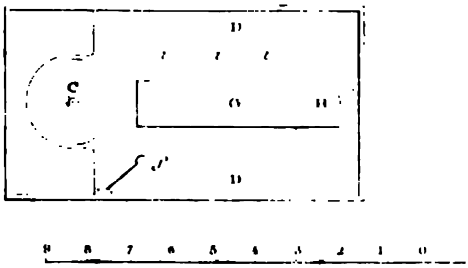


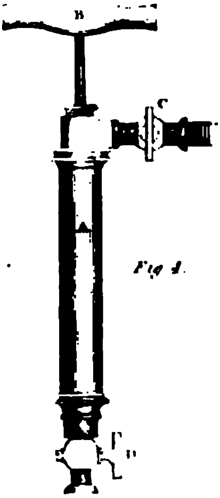
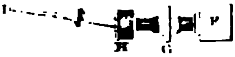


Fig 4.

Fig 6.



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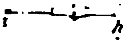

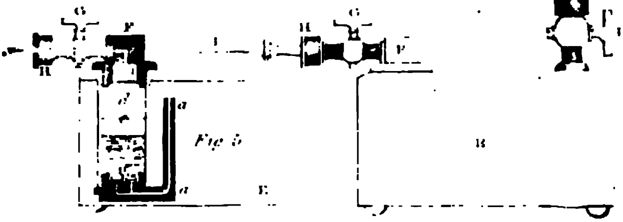

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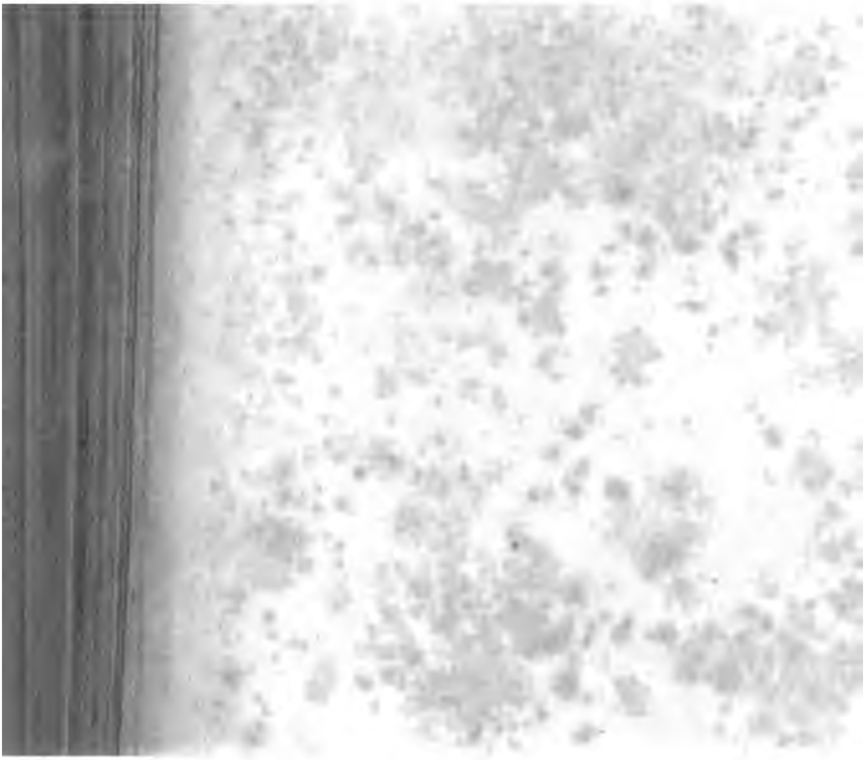

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